N72 33013
NASA CR-112181

AIRCRAFT SYSTEMS DESIGN STUDIES EMPLOYING ADVANCED TRANSPORT TECHNOLOGIES

By

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MANAGER ADVANCED AIRCRAFT TECHNOLOGIES
October 5, 1972

Prepared Under Contract NAS1-10900

by

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Hampton, Virginia

for

LANGLEY RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY

By about 1985 technological advances will have necessitated a new generation of commercial aircraft in order to remain ecologically acceptable and economically competitive in the domestic and world transportation markets. The current generation of commercial aircraft will be technologically outdated by then. Design studies were conducted of near-sonic (M .98) advanced technology transport type aircraft as a replacement in that era. Among the advanced technologies investigated were the supercritical wing, area ruling, composite materials and load alleviation. These studies revealed that with the application of advanced technologies, replacement aircraft were feasible in both the business jet and large transport categories.

The area ruled fuselage of near-sonic advanced technology transports offers more seating space in the expanded section while providing slightly less space in the area of the wing integration than current technology fuselages. For M .98, the area ruled fuselage shape is more practical in large transports, over 170 passengers, and business jets. The 20 to 170 passenger configurations utilizing area ruling do not appear practical for near-sonic transports because of head height limitations over the wing.

The highly swept supercritical wing could be lighter, thicker and could carry more fuel than a conventional wing at any Mach Number.

Due to the increased wing sweep required at the higher Mach numbers, the inboard area of the wing must be increased if a conventional type landing gear is used. Conventional tricycle and wing podded landing gear systems were evaluated. In addition, an air cushion landing system was considered and appears promising. The wing podded arrangement offers more advantages than the conventional tricycle arrangement at the higher Mach numbers.

The review of aircraft configurations for flight evaluation of the advanced technologies showed that a business jet size research aircraft was a suitable candidate and appeared the most economical. An airplane incorporating supercritical aerodynamics, active control systems and composite material construction could be designed, produced, tested and evaluated for approximately 25% more cost than that of a conventional aircraft of the same size. The additional costs are assessed to the complexities associated with active control systems and fabrication of the supercritical wing utilizing composite materials. Retrofitting multiple technologies to existing aircraft does not appear to be practical from a cost standpoint at the higher Mach numbers, because of the amount of structural

modification that would be required to meet the supercritical technology.

A load alleviation system was investigated. A typical system could reduce in-flight loads possibly up to 50%; however, the ground maneuver and taxi loads would not be reduced by these flight devices. To reduce the structural weight by the use of such a system would necessitate a reduction in FAR-25 design criteria.

Computer programs were developed to support the various design disciplines. These programs include weights, stress, flutter, loads, propulsion, and mission analysis routines.

INTRODUCTION

The supercritical wing concept, introduced by Dr. R. Whitcomb of NASA, Langley's High Speed Aerodynamics Division, unveiled new possibilities for flight in the transonic regime. Utilization of this and other advanced technologies such as area rule, load alleviation, composite materials necessitated investigations in the areas of high lift devices, wing to fuselage integration, and alternate aircraft configurations. Improved data is continually being generated in the above areas of advanced technologies and is being incorporated in advanced system design studies as developed.

Design concepts of these technologies require detail definition and integration into system designs to serve as the reference for follow-on hardware concepts. The study results have established that these new technologies can be directed toward the achievement of improved performance or economy. These benefits may be used to compensate for the penalties associated with reduced noise requirements anticipated to make future aircraft ecologically acceptable while remaining economically competitive. In addition, the studies have assisted in assessing technology modifications which are necessary to develop compatible effective cost and economic study programs.

This document covers the work accomplished in the system and design integration studies. The objective of this work is to define and assess the application of the advanced technology most likely to result in a superior next-generation, high subsonic/sonic CTOL transport aircraft system.

SYMBOLS

ACS	Active Control System
A. R.	Aspect Ratio
ATA	Airline Transport Association
ATT	Advanced Transport Technology
b	Wingspan
c	Chord
c/4	Quarter Chord
C_L	Coefficient of Lift
C_D	Coefficient of Drag
CTOL	Conventional Take-off and Landing
DOC	Direct Operating Cost
ft.	Foot
FBW	Fly by wire
g	Force of Gravity
GELAC	Lockheed Georgia Company
GW	Gross Weight
HTC	Hampton Technical Center
in.	Inch
IPAD	Integrated Parametric Aircraft Design
l	Length
lbs.	Pounds
loc	Location
LRC	Langley Research Center
M	Mach number

SYMBOLS (Continued)

MAC	Mean Aerodynamic Chord
max.	Maximum
min.	Minimum
NASA	National Aeronautics and Space Administration
N. M.	Nautical Miles
O. W. E.	Operating Weight Empty
P&WA	Pratt and Whitney Aircraft
RDT&E	Research, Design, Test and Evaluation
Sta.	Station
SCW	Supercritical Wing
S	Wing Area
T. O.	Take-off
TOGW	Take-off Gross Weight
W/S	Wing Loading
WBL	Wing Butt Line
WRP	Wing Reference Plane
ξ	Spanwise Distance from Plane of Eta Station - % Wing Span Symmetry Relative to Total Wing Span
Λ	Sweep Back
2W - 1T	Two Wing - One Tail
4W	Four Wing

ADVANCED AIRCRAFT TECHNOLOGY

INTEGRATED SYSTEMS DESIGN

The design approach is presented in a System Design Integration Chart (Figure 1). The interaction between the design disciplines is required in order to provide in-depth integrated systems design studies.

SUPERCRITICAL TECHNOLOGY

Area Rule Fuselage

The primary design consideration in determining the shape of the fuselage is the overall fineness ratio of the area rule curve, which determines the maximum to minimum fuselage diameter. The sensitivity of the area rule can be seen by comparing the fineness ratios of 8.6 and 9.6 on a Mach .98 cruise aircraft (Figures 2 and 3). The comparison shows an increase of 15% for the maximum and 19% for the minimum diameter for a one point decrease in fineness ratio.

Compound curvature is a driving variable in increasing both aircraft weight and air frame fabrication cost. A finite cabin width and length can only accomodate a discrete number of seats. An optimum fuselage diameter would be constant for a multiple of seat width. Diameter differences reduce the seating efficiency, thus increasing DOC.

The location of the minimum diameter is influenced by wing location. When the maximum wing cross sectional area coincides with the apex of the area rule curve, the fuselage minimum diameter is established.

The maximum diameter for any fineness ratio is an advantage; there is little structural penalty and both passenger and cargo volume is increased. For example, a 300 passenger area ruled aircraft, with a fineness ratio of 9.1, has a maximum diameter that is 23 inches larger than the DC10 and five inches larger than the 747. This larger volume for passengers, forward of the wing box, is also a significant advantage in the design of a Mach .98 executive jet.

Highly Swept Wing

In addition to the area ruled fuselage, the 42.5 degree swept wing, dictated by Mach number .98, created a major problem in integrating the landing gear. Basically, the wing thickness in the main gear area was inadequate for the support of the main gear. In addition, there was insufficient wing chord aft of this location to accomodate high lift devices. Therefore, it was necessary to increase the wing cross sectional area at the fuselage intersection in order to increase its local thickness for landing gear structure and provide space for the inboard flap.

In terms of area ruling, the "batting" of the wing added wing cross sectional area which was removed from the fuselage, further reducing its minimum diameter. The additional wetted area added by "batting" the wing is shown in progressive steps in Figure 4. The basic wing for this configuration has an aspect ratio of 6.3 and 2400 square feet of wing area. Initially, the landing gear stowage requirement and the accomodation of inboard flaps were inadequate on this baseline configuration. In order to alleviate this, three iterations were made to add the necessary wing area. The batted wing configuration had an area increase of 837 square feet, which reduced the aspect ratio to 5.25. The reduced aspect ratio will cause additional drag, which will lower the cruise Mach number or will require larger engines. A more detailed investigation of the wing geometry will be required to assure the optimum wing configuration if wing "batting" is utilized to provide landing gear stowage and accomodation for high lift devices.

Landing Gear Integration

As alternates to "batting" the wing, other landing gear concepts were investigated. The most promising is a wing pod stowage for the main gear. This concept adds only 300 square feet of area to the above wing, requires no wing "batting," and no decrease in minimum fuselage diameter. Additionally, the inboard flap area is more aerodynamically efficient due to the side plate effects of the fuselage and landing gear pod. The podded system should be lighter than the batted systems as the gear is positioned under the rear beam.

An Air Cushiong Landing System was another concept investigated where no wing batting was necessary and current contractor estimates show a modest weight savings over conventional gear. Ground handling and aerodynamic characteristics have not been fully supported and will require further investigation.

Supercritical Wing

To better understand the characteristics of a supercritical wing, studies were conducted to aid in selection of a baseline wing for evaluation. The System Design Integration approach was used to investigate the system design concepts on the baseline wing. These concepts included basic load analysis, wing component design, flutter analysis, and statistical weight program development. Studies provided realistic inputs for a matrix of aircraft sizes into many different programs, such as the low and high speed wind tunnel models, flutter models, and Integrated Parametric Aircraft Designs (IPAD) computer designs.

A comparison between a conventional aircraft (727-200) wing and a supercritical wing (SCW-1-156) of equal area was made to show the differences in size, shape, weight, etc. The planform of the two wings are shown in Figure 5. This figure shows the sweep of 32.5 degrees for the 727 and 42.5 degrees for the SCW-1-156. The increase in sweep for the SCW (dictated by the. 98 cruise Mach number) impacts the wing box. Two major effects are that it is longer for a given wing area and span, and it is narrower because of larger high lift system requirements. Both result in weight increases. However, when compared to a 727 type wing with 42.25 degree sweepback, the thicker, more efficient cross section of a supercritical airfoil is 11% lighter. The thicker wing box also provides a significant increase in wing fuel tank capacity, approximately 14%, which, in turn, provides more wing fuel weight and, thus, additional bending relief.

Cost

In order to test the advantages of supercritical technology at near-sonic speed, a flight test program is indicated.

The anticipated cost of experimental aircraft incorporating supercritical technology for both conventional and composite materials in the wing was reviewed. A study was conducted to establish a credible program for estimating costs as a function of aircraft weight. Parts of NASA working papers were integrated into a single program. The program showed good correlation in a comparative study utilizing a system study contractor's (General Dynamics) estimating and cost data.

The results of this study are presented in Figure 6. Two sets of aircraft at various gross weight, one with an aluminum wing, curves 3 and 4, the other with a composite wing, curves 1 and 2, show rapid cost increases as weight increases. The studies were limited to aircraft from 20,000 pounds to 250,000 pounds gross weight. As an example, the cost of an aircraft weighing 60,000 pound with an aluminum wing would cost from 62.5 million to 65 million dollars, depending on design cruise Mach number. Applying advanced technology, a composite wing, with load alleviation, would cost 80 to 85 million dollars. Therefore, the additional cost of developing an advanced technology aircraft system incorporating a composite wing with load alleviation is 17.5 to 20 million dollars, depending upon Mach number requirement.

Research Aircraft

A general arrangement of candidate aircraft to demonstrate advanced technology is depicted in Figure 7. The cockpit has side-by-side seating of pilot and copilot with ejection seats. The instrument panels and consoles can represent those of a large multi-engine jet. There is sufficient area for instrumentation consoles and flight observers to maintain flight monitoring as necessary. The wing is large enough to accomodate advanced technology load alleviation devices and to observe scaling effects on primary structure.

The study indicated that a .98 Mach number business jet is feasible. An existing business jet as compared to the development of a new aircraft was considered. Investigation of existing business jets was conducted to check their viability as advanced technology research aircraft. A modified Lear Jet, with two 10 foot plugs added to meet the proper fineness ratio of 9.6 as shown in Figure 8, was one of the configurations studied. The cross-hatched area is all new structure and the shaded area is the modified form required to approximate the area rule curve. Very little of the original aircraft structure could be used. Conversion or modification of existing aircraft, such as the Boeing 737, 727, and the DC 9 are being considered for application as experimental aircraft to demonstrate advanced single and integrated technologies.

Contractor Comparisons

The three system contractors presented their configurations for an experimental advanced technology aircraft. A comparison of their sizes and geometry are presented in Table I. The variations in their alternate configurations indicate that their predictions for the future commercial aircraft market are diverse. For example, the alternate configurations TOGW varied from 247,000 to 340,000 pounds, and Mach numbers varied from .90 to .98. Range remained fairly constant at 3000 nautical miles. Based on the above, there appears to be little correlation on size of the airplane for the replacement period. The air transportation requirements for the 1985 period should be more firmly established.

ACTIVE CONTROL SYSTEMS

One of the advanced technologies under investigation is an active control system (ACS). The main advantage of ACS is the reduction in maximum flight load excursions. This allows the use of a longer endurance limit for the structural materials for longer aircraft lifetime or a reduction in material gages for a reduction in aircraft weight. Along with this structural benefit, there is a significant improvement in ride quality. It appears that the magnitude of the flight loads can be reduced by 50%; however, the ground maneuver and taxi loads are not reduced by these flight devices. FAR-25 design criteria would have to be reduced in order to realize any weight savings.

Various systems have been designed and tested in the recent years as load alleviation devices, and are presented in Figure 9. The twisting wing tip in Figure 9 was presented in a Langley working paper and is a theoretical concept that has not been tested. A Spoiler Slot Deflector (SSD) was examined. A study is underway to determine quantitative data on the SSD advantages and disadvantages. The main concerns are response time, added drag, and the resultant change in pitching moment.

The preliminary investigation was concerned with the extent of load alleviation that could be achieved through ACS while still maintaining compatibility with the ground loads. Figures 10 through 13 relate the potential reduction in maximum wing bending moment from using load alleviation for one and two engines on each wing, and for a clean wing configuration. The magnitude of the airloads are depicted with and without load alleviation. Additionally, the bending relief provided by wing-mounted engines can be determined by comparing the maximum excursions in each configuration.

COMPUTER PROGRAM TECHNOLOGY

To assist the advanced transport evaluation studies, several computer programs were developed in FORTRAN language for processing on the Control Data 6600 System at NASA/LRC. Reference is made to Table II which lists the current operational programs. Included are programs to compute aerodynamic wing geometry data; loads and flutter; mission analysis, which determines flight profiles, component sizing and overall efficiency; installed engine performance; stress analysis; weight; and aircraft costs.

Mission Analysis

A computer program to evaluate flight profiles including take-off, climb, cruise, descent and landing has been developed and is operational. Using this program, comparative studies were made to size major aircraft components, determine salient characteristics of performance and flight profiles, and evaluate the overall efficiency at which selected advanced technology configurations should operate. Mission/airframe combinations which best reflect the conclusions drawn from these studies were synthesized.

The Mission Analysis program, which provides an estimation of aerodynamic performance from take-off to landing, has been broken down into two major segments for study purposes. First, the utilization of advanced computer technology andFortran IV programming was used for both current and suggested future developments. Secondly, this computer technology was applied in analyzing various mission profiles for advanced transport configurations ranging in size from 156 to 300 passengers. The computer program was developed in routines, one for each segment of the flight profile, climb, cruise, and descent. These segment routines were combined into a single integrated closed loop missions program called MISSIONS. The segmented basis allows flexibility in future modifications and improvements. This relatively refined and detailed program has a built-in capability for application to subsonic or transonic turbojet transport.

The flight profile, Figure 14, is presently incorporated in the MISSIONS computer program and is based on the Air Transport Association (ATA) domestic rules, which include time, distance, fuel to climb and descend, and reserve fuel are corrected for the effects of altitude and velocity changes.

The MISSIONS program inputs, Figure 15, consists of weight, propulsion and aerodynamic information. The weight data is obtained from a computer routine developed from statistical data and deterministic inputs from calculated design and weights data. The propulsion routine corrects engine data from uninstalled performance results supplied by engine manufacturers. The installation corrections are inlet recovery, nonreference nozzle, thrust reversers, power extraction, and service airbleed.

Aerodynamic data is derived from drag polars from wind tunnel test data which has been corrected to full scale using current industry technique. This technique involves calculation of the minimum incompressible parasite drag using flat plate theory and form factors. A separate computer program was developed to handle this calculation. With proper weights and propulsion information, a rapid mission analysis response to any request on a fixed geometry and engine configuration can be provided.

The MISSIONS program outputs, Figure 16, are weights, range, fuel, and time information which are calculated for the total mission and for the mission segments. The results are then inputs for the economic evaluation program.

Two options of the MISSIONS computer program are available for the total mission where the aerodynamic geometry, payload, and design Mach number are held constant. This is shown in Figure 17. Option one computes the range for a fixed ramp weight while option two allows the ramp weight to be calculated as a function of fixed range. There are other options available for the cruise, descent and reserve.

Future capabilities and developments, Figure 18, may be derived from the MISSIONS computer routine and proposed airport performance programs. Continual modifications will be made to the MISSIONS program to increase its efficiency and usefulness in advanced transport technology. Take-off and landing routines will be written to complete an airport performance program in rounding out an entire mission.

To illustrate the mission analysis capability, a hypothetical trijet configuration with a 300 passenger payload was selected. The trijet configuration, which consists of an airplane with two wing-mounted engines and one straight duct engine mounted in the vertical tail, is shown in Figure 19. This particular configuration has a 42 degree swept wing (Mach .98 design). The wing planform was developed through supercritical technology and is a 3000 nautical mile range mission with a 300 passenger payload of 61,500 pounds and a cruise Mach number of .98. The configuration was parametrically optimized for wing area and engine size. The effects of start cruise altitude were also evaluated. The parametric studies include range, wing area, start cruise altitude, engine sizing and sensitivity effects of drag and operating weight empty.

The variation of ramp weight with wing area and start cruise altitude is shown in Figure 20. For each maximum start cruise altitude, there is a wing area at which the ramp weight is a minimum. This plot shows the fuel cut off line. For the same calculations, the variation of sea level static thrust with wing area and start cruise altitude is presented in Figure 21. This curve shows the minimum ramp weight line from the previous figure. The operating altitude region for a wing area of 3,540 square feet, an initial cruise weight of 450,000 pounds, and an engine thrust rating of 50,000 pounds sea level static thrust is shown in Figure 21. For aircraft flying at transonic speeds, the operating region may be severely limited by the maximum and minimum cruise altitudes. In addition, Figure 22 illustrates that the drag exceeds the maximum cruise thrust available at a minimum and maximum altitude restricting the operational altitude.

Figure 23 shows the effect of engine size on operating altitude. As engine size increases, the operating altitude range also increases, and the maximum cruise altitude is higher. Also, an engine size reduction could make the aircraft incapable of flying at Mach .98 for the conditions shown.

The variation of specific range with altitude for this aircraft at Mach .98 is presented in Figure 24. The maximum power setting determines the upper and lower altitude limits. It should be noted that there is a weight at which the aircraft can no longer fly at Mach .98.

In summarizing the parametric characteristics, Figure 25, of the trijet configurations, studies were made on the effects of start cruise altitude on ramp weight, sea level static thrust, wing area, start cruise wing loading, total fuel, and operating weight empty. With the wing area being optimized for minimum ramp weight, studies revealed a 13,500 pound increase in ramp weight as the start cruise altitude varied

6,000 feet starting at 33,000 feet. Also, the sea level static thrust rating ran from 47,500 pounds to 55,500 pounds and thrust to weight ratio from .31 to .35, respectively, over the same start cruise altitude region. To fly at start cruise altitude of 33,000 feet, it takes a wing reference area of 3250 square feet which increases to 4000 square feet as start cruise altitude begins at 39,000 feet. Start cruise wing loading decreased 17% from 137 lb/ft^2 to 114 lb/ft^2 and total fuel showed very little variation with start cruise altitude, although operating weight empty increased 6%.

CONCLUSIONS

Near-sonic Advanced Technology Commercial Transports will become a reality by 1985 if these technologies are, in fact, implemented, tested, and evaluated through an integrated flight system. Benefits of the supercritical wing and advanced transport technology have been established. Technologies requiring in-depth study and development are those attendent to slow speed flight. Presently, areas that have been identified are the development of more efficient high lift devices and the applications of FBW and ACS. Main landing gear systems, whether podded or air cushioned, require evaluation from aerodynamic and ground maneuvering standpoints to assure selection of the optimum system for advanced technology transport aircraft.

An experimental testbed aircraft appears to be the only means of obtaining accurate technology support data. Aircraft development programs are expensive and escalate with increasing aircraft weight. Therefore, the selection of the aircraft to be used is a prime factor in acquiring the most data for the dollar cost. The trades between a larger, modified current technology aircraft to test a single technology must be compared with the development of a smaller aircraft which could incorporate multiple technologies. For example, new technologies could include composites, ACS, FBW, as well as scaling effects.

The MISSIONS program, along with weights and other supporting computer programs, should be expanded to supersonic, hypersonic, and STOL aircraft. Other parameters that could be investigated for incorporation into the MISSIONS program are noise and terminal approach.

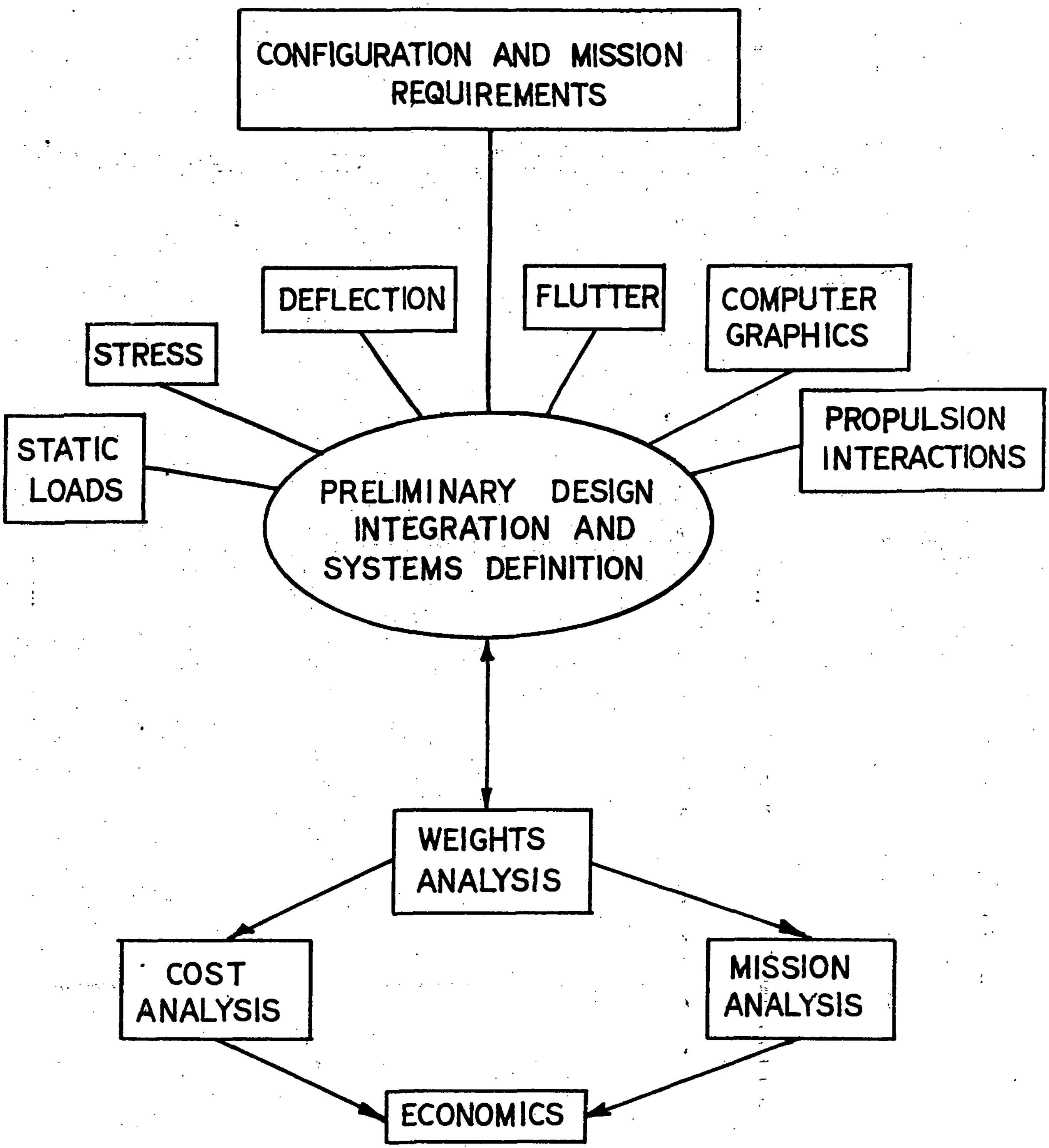

CONFIGURATION AND MISSION REQUIREMENTS
DEFLECTION
FLUTTER
COMPUTER GRAPHICS
STRESS
STATIC LOADS
PROPULSION INTERACTIONS
PRELIMINARY DESIGN INTEGRATION AND SYSTEMS DEFINITION
WEIGHTS ANALYSIS
COST ANALYSIS
MISSION ANALYSIS
ECONOMICS

FIGURE 1

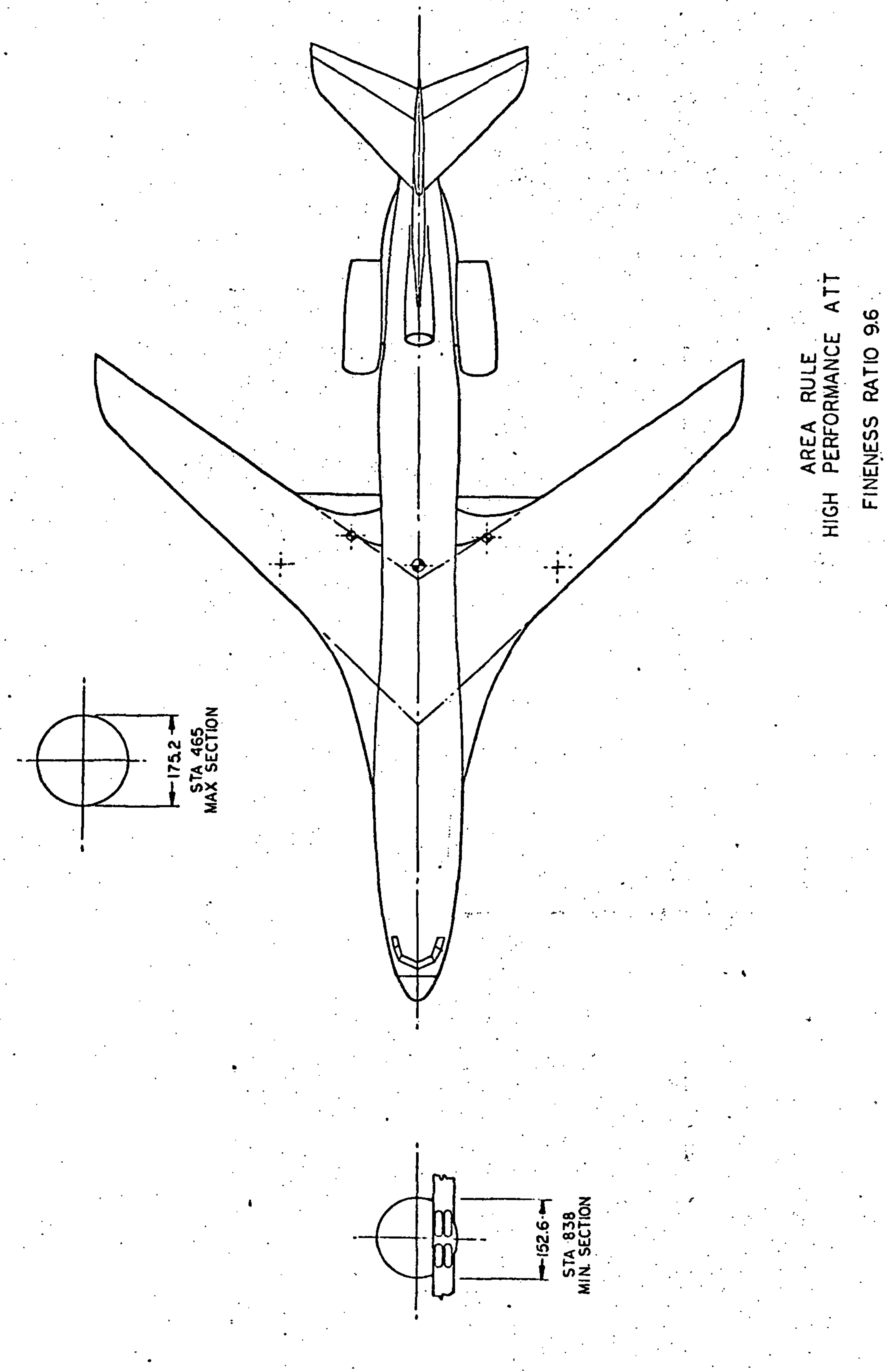

AREA RULE
HIGH PERFORMANCE ATT
FINENESS RATIO 9.6
175.2
STA 465
MAX SECTION
152.6
STA 838
MIN. SECTION

FIGURE 2

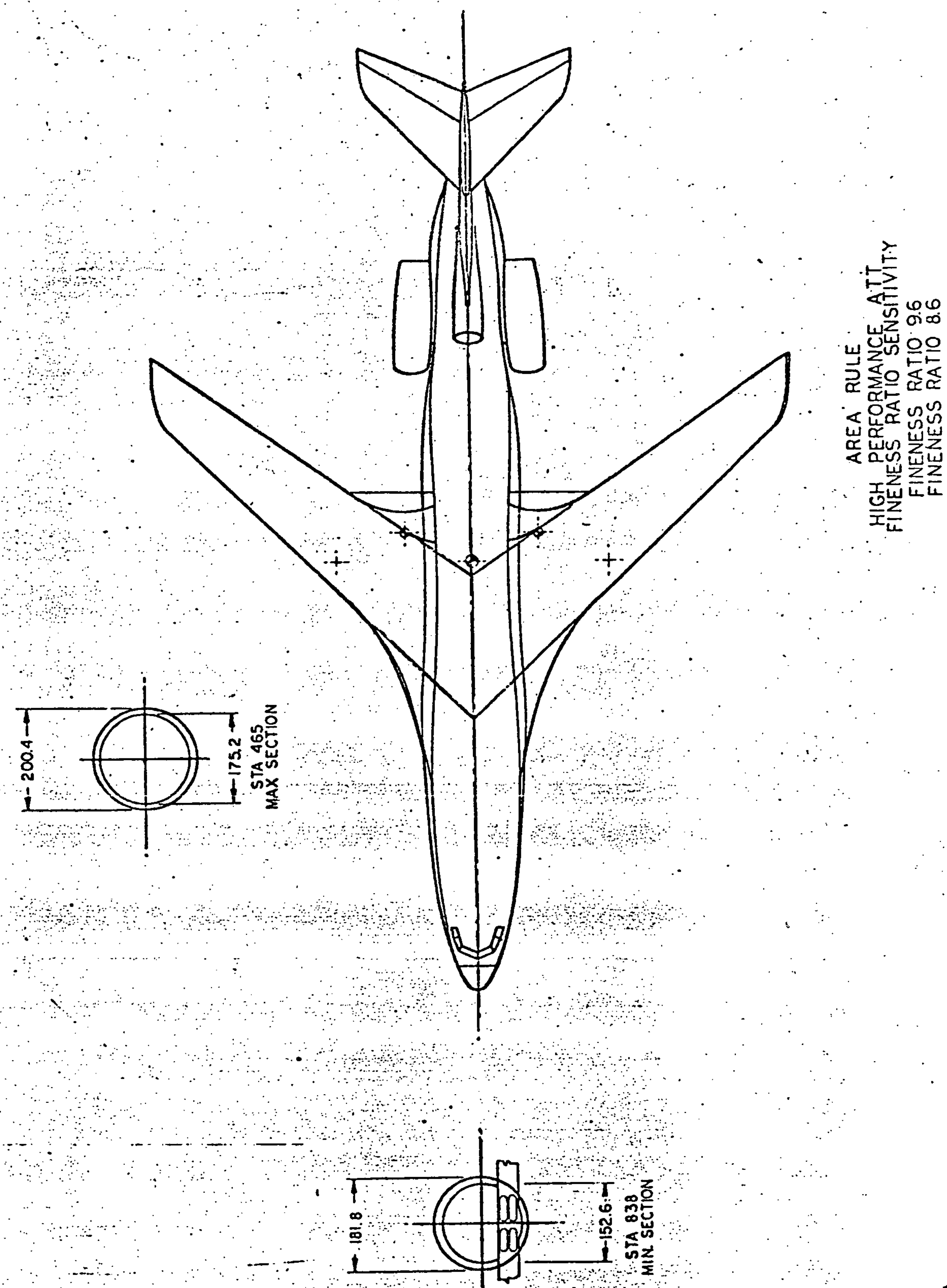

AREA RULE
HIGH PERFORMANCE ATT
FINENESS RATIO SENSITIVITY
FINENESS RATIO 9.6
FINENESS RATIO 8.6
200.4
175.2
STA 465
MAX SECTION
181.8
152.6
STA 838
MIN. SECTION

FIGURE 3

AREA RULE
HIGH PERFORMANCE ATT
WETTED AREA

WETTED AREA WING TE BAT	
PRELIMINARY	139.00 ft^2
BASELINE	356.00 ft^2
CONTRACTORS	837.00 ft^2
BASELINE PRELIM	217.00 ft^2
CONTRACTORS - BASELINE	281.00 ft^2
LANDING GEAR PODS	300.00 ft^2

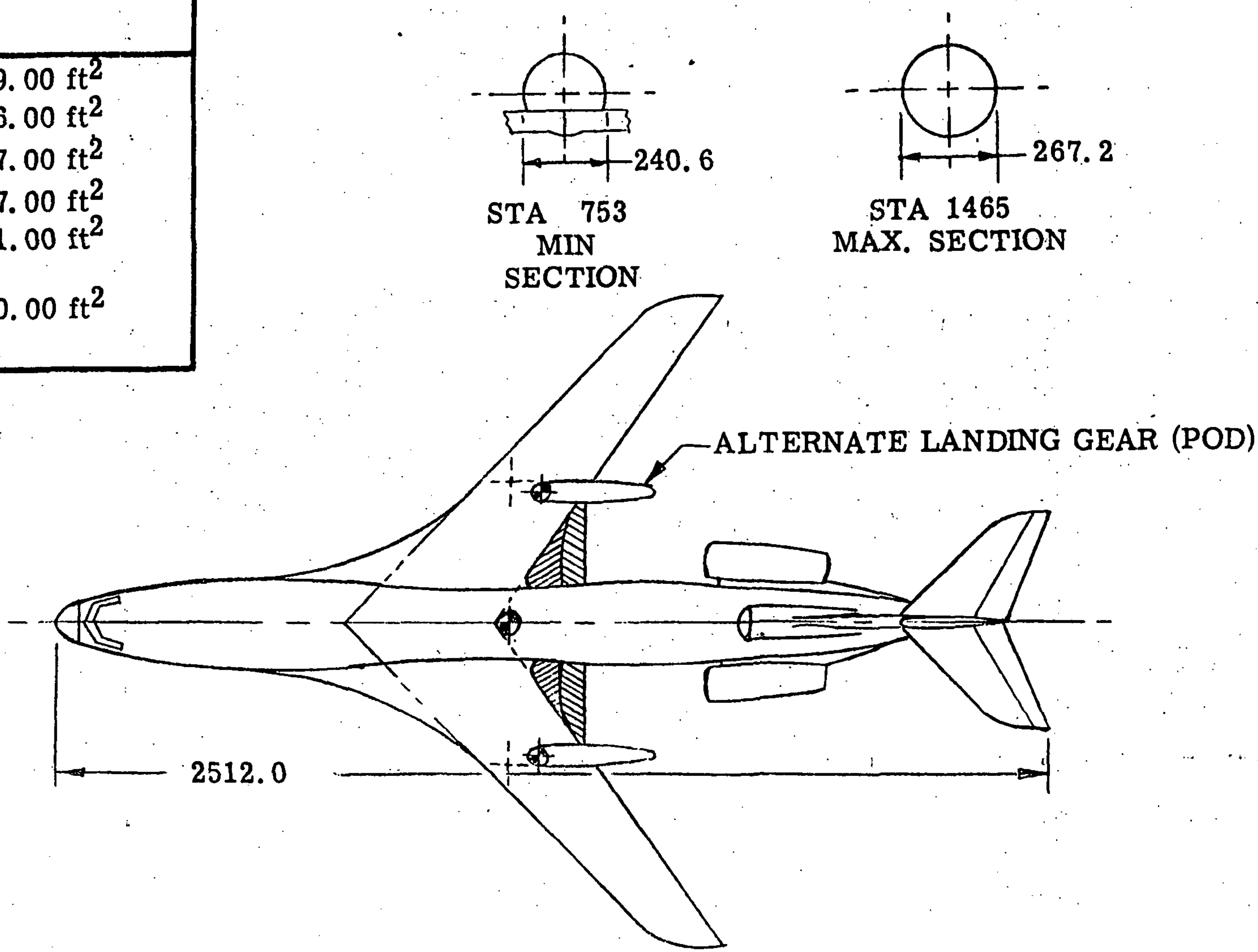
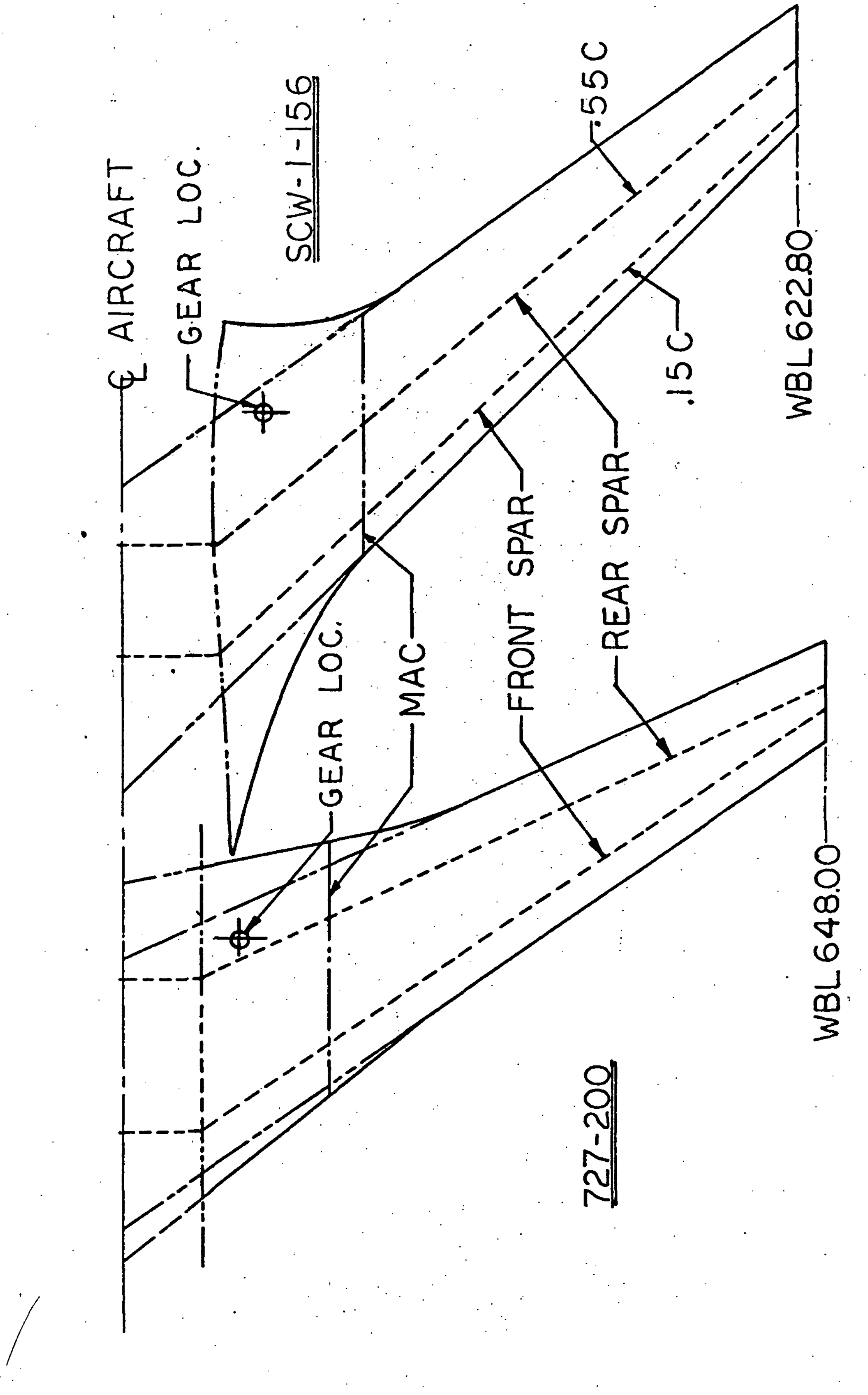


FIGURE 4



WING PLAN FORM COMPARISON

19

FIGURE 5

TOTAL R. D. T. AND E. COSTS

PROPOSED EXPERIMENTAL AIRCRAFT

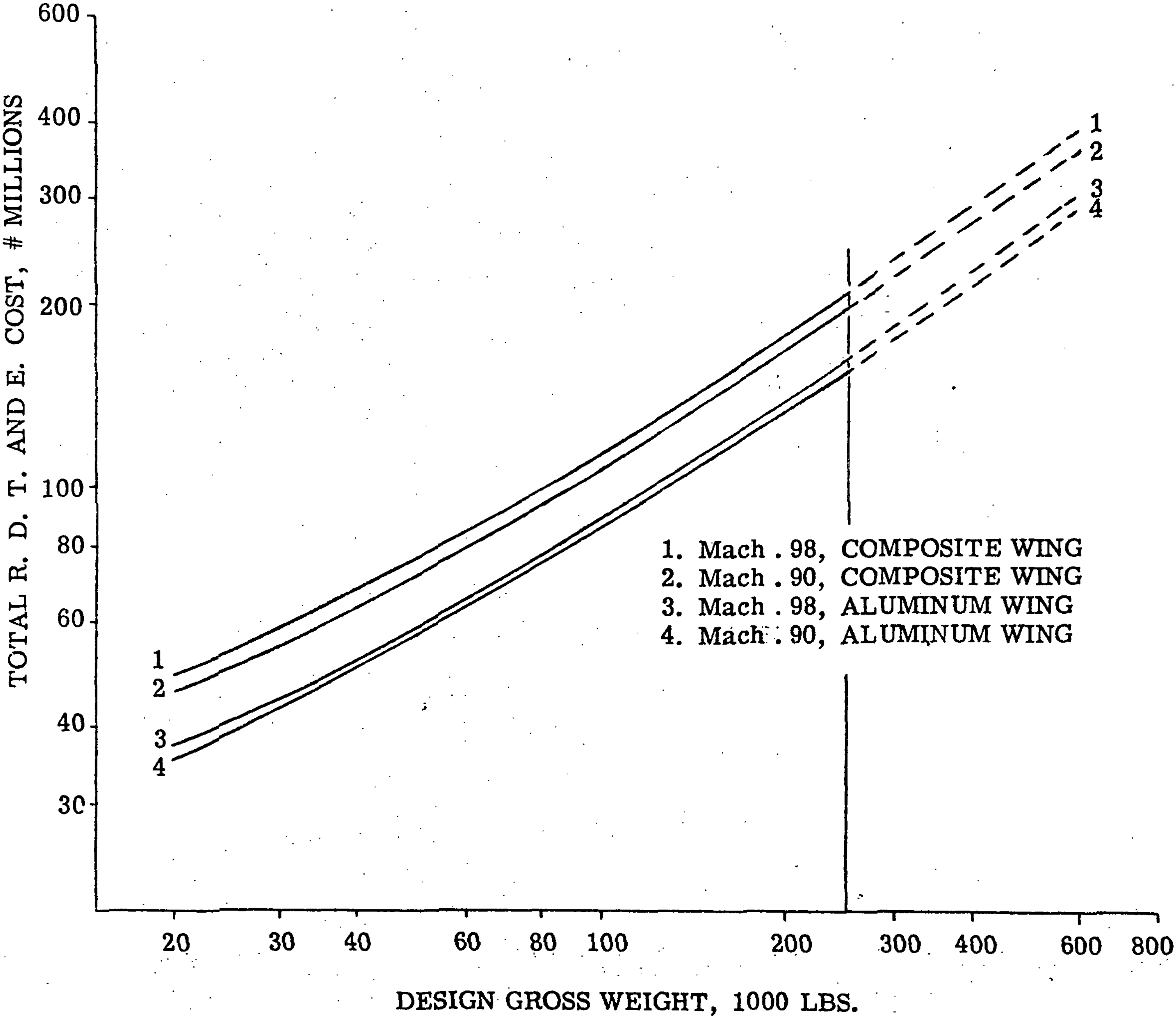


FIGURE 6

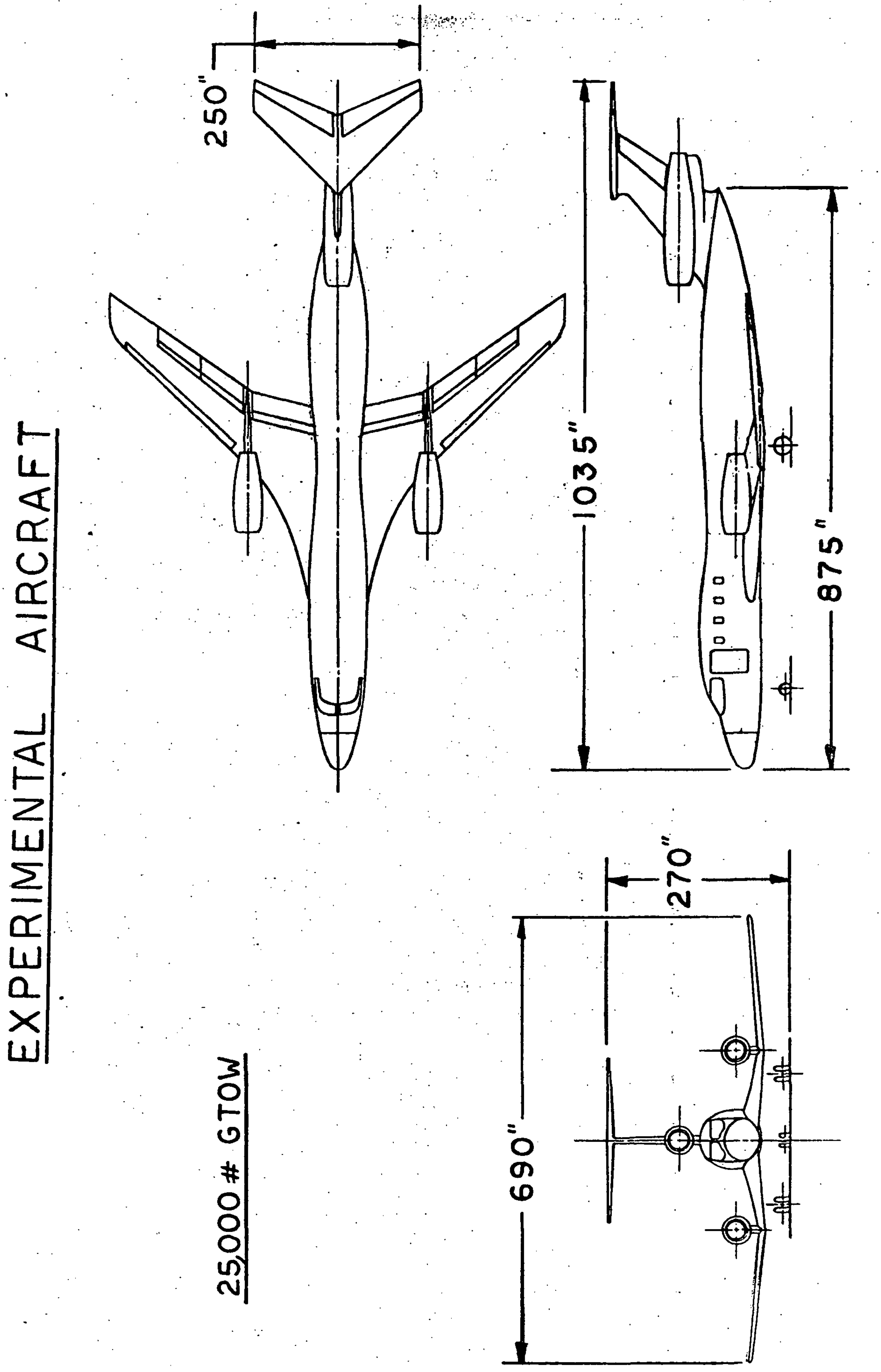


FIGURE 7

LEARJET MODIFICATION
FOR EXPERIMENTAL AIRCRAFT

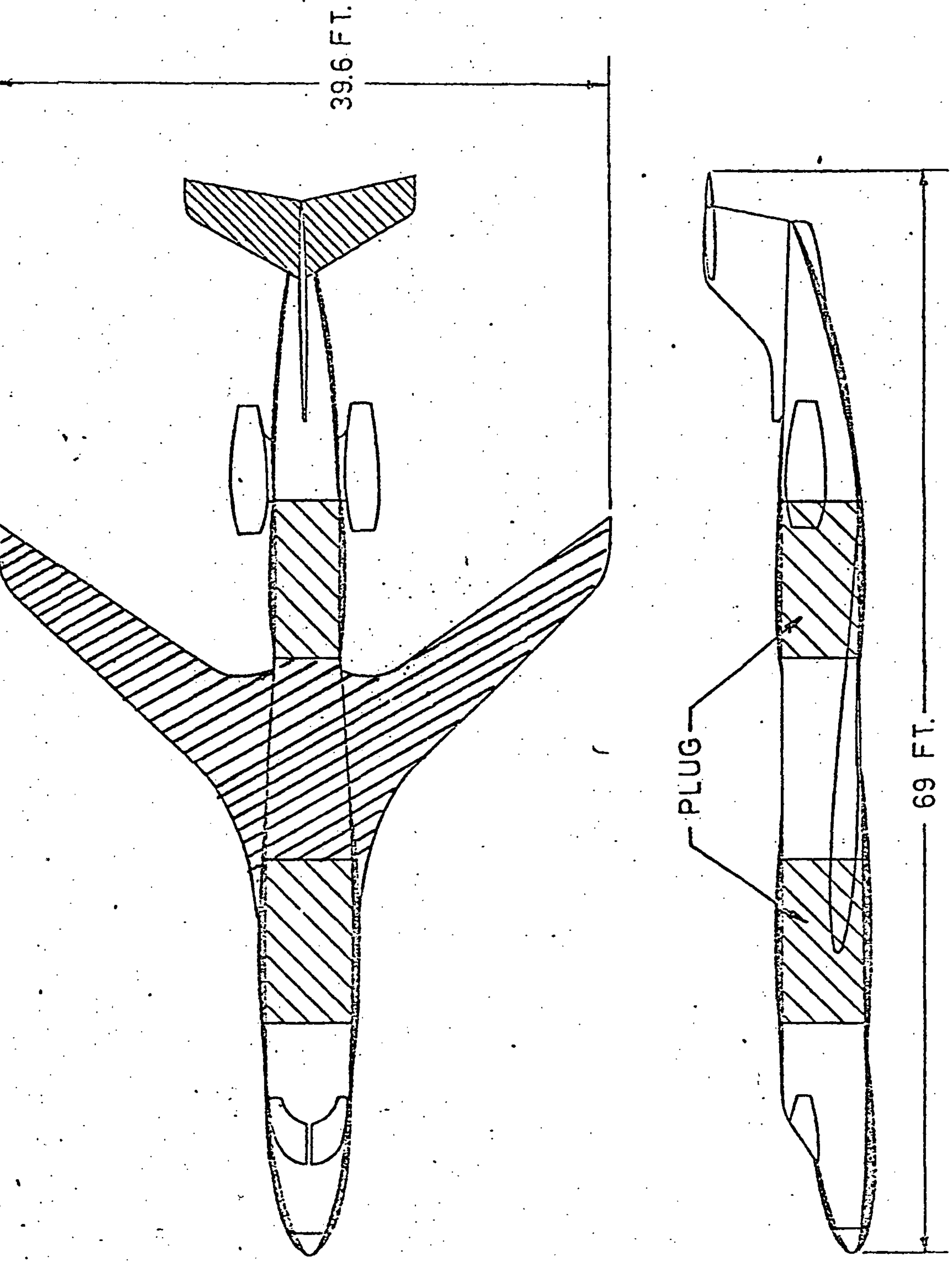
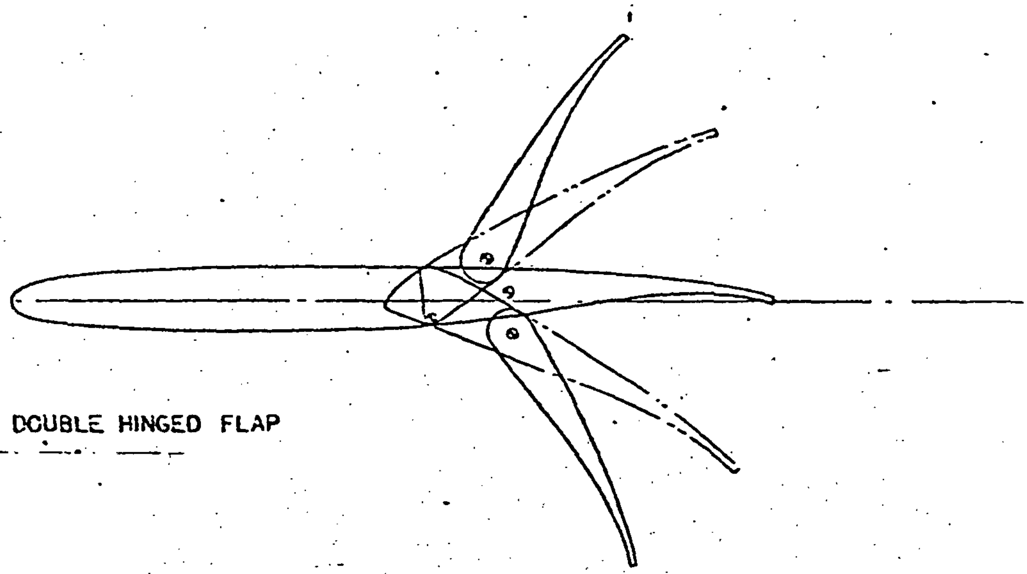
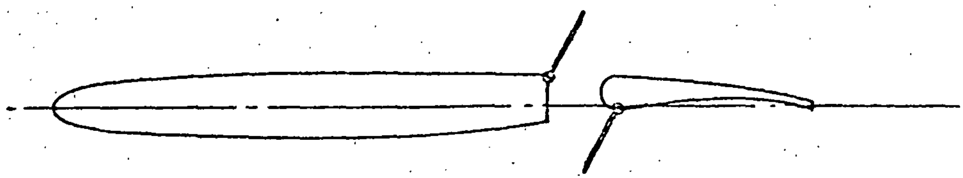


FIGURE 8

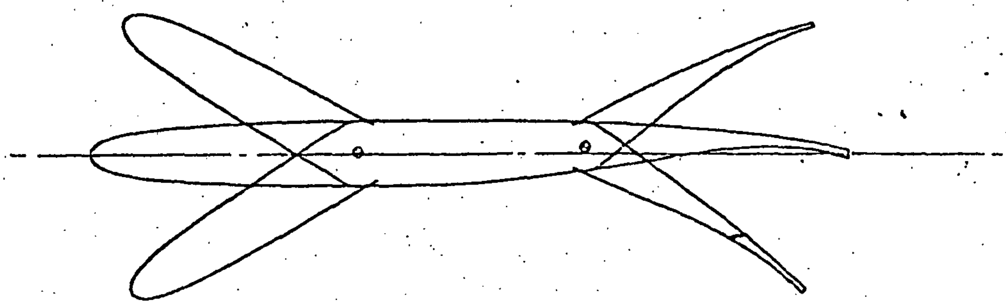
LOAD ALLEVIATION DEVICES



DOUBLE HINGED FLAP



SPOILER SLOT DEFLECTOR



TWISTING WING TIP

FIGURE 9

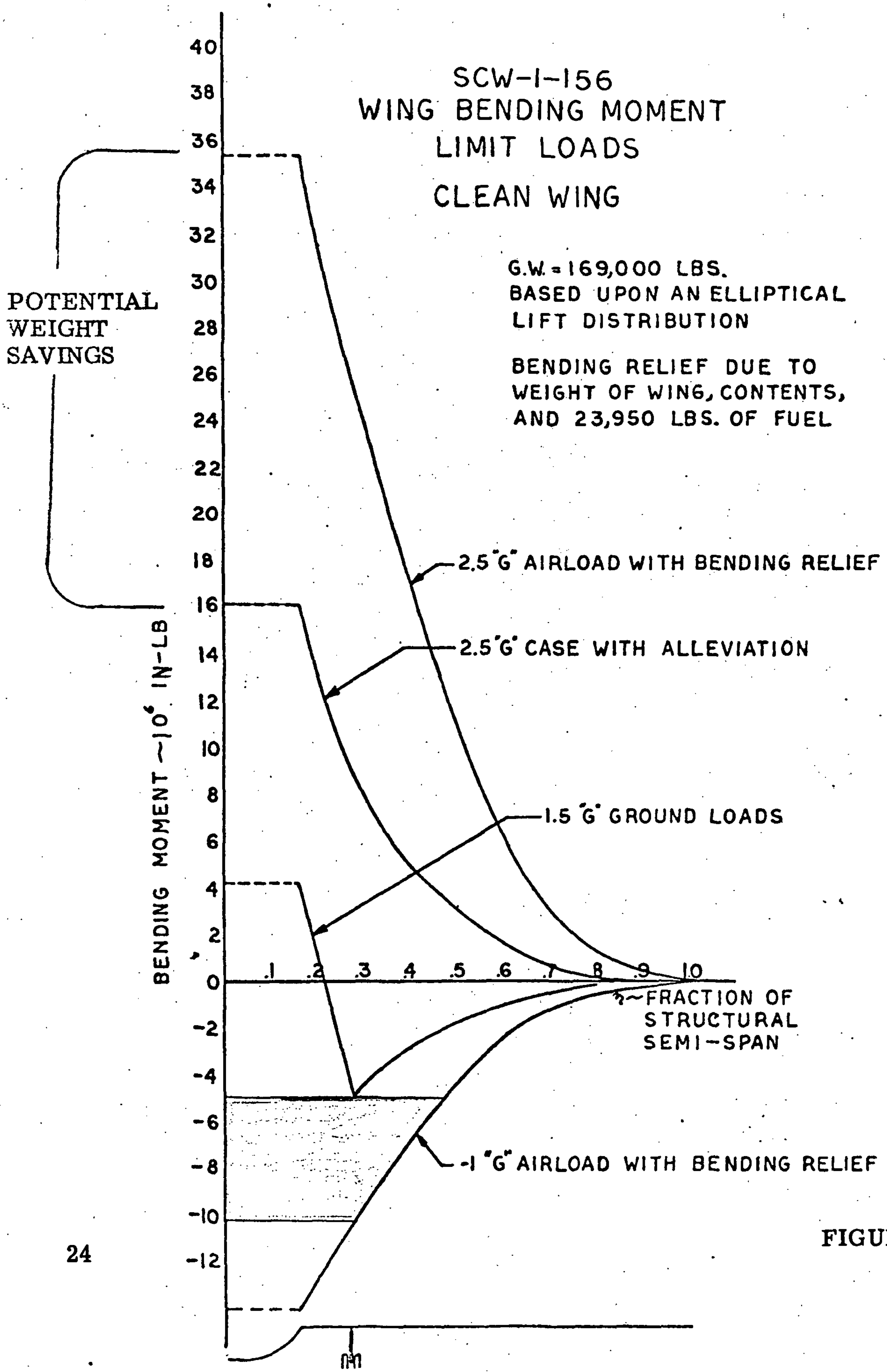

SCW-1-156
WING BENDING MOMENT
LIMIT LOADS
CLEAN WING
G.W. = 169,000 LBS.
BASED UPON AN ELLIPTICAL LIFT DISTRIBUTION
BENDING RELIEF DUE TO WEIGHT OF WING, CONTENTS, AND 23,950 LBS. OF FUEL
POTENTIAL WEIGHT SAVINGS
2.5 "G" AIRLOAD WITH BENDING RELIEF
2.5 "G" CASE WITH ALLEVIATION
1.5 "G" GROUND LOADS
-1 "G" AIRLOAD WITH BENDING RELIEF
BENDING MOMENT ~ 10^6 IN-LB
η ~ FRACTION OF STRUCTURAL SEMI-SPAN
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
.1 .2 .3 .4 .5 .6 .7 .8 .9 1.0

FIGURE 10

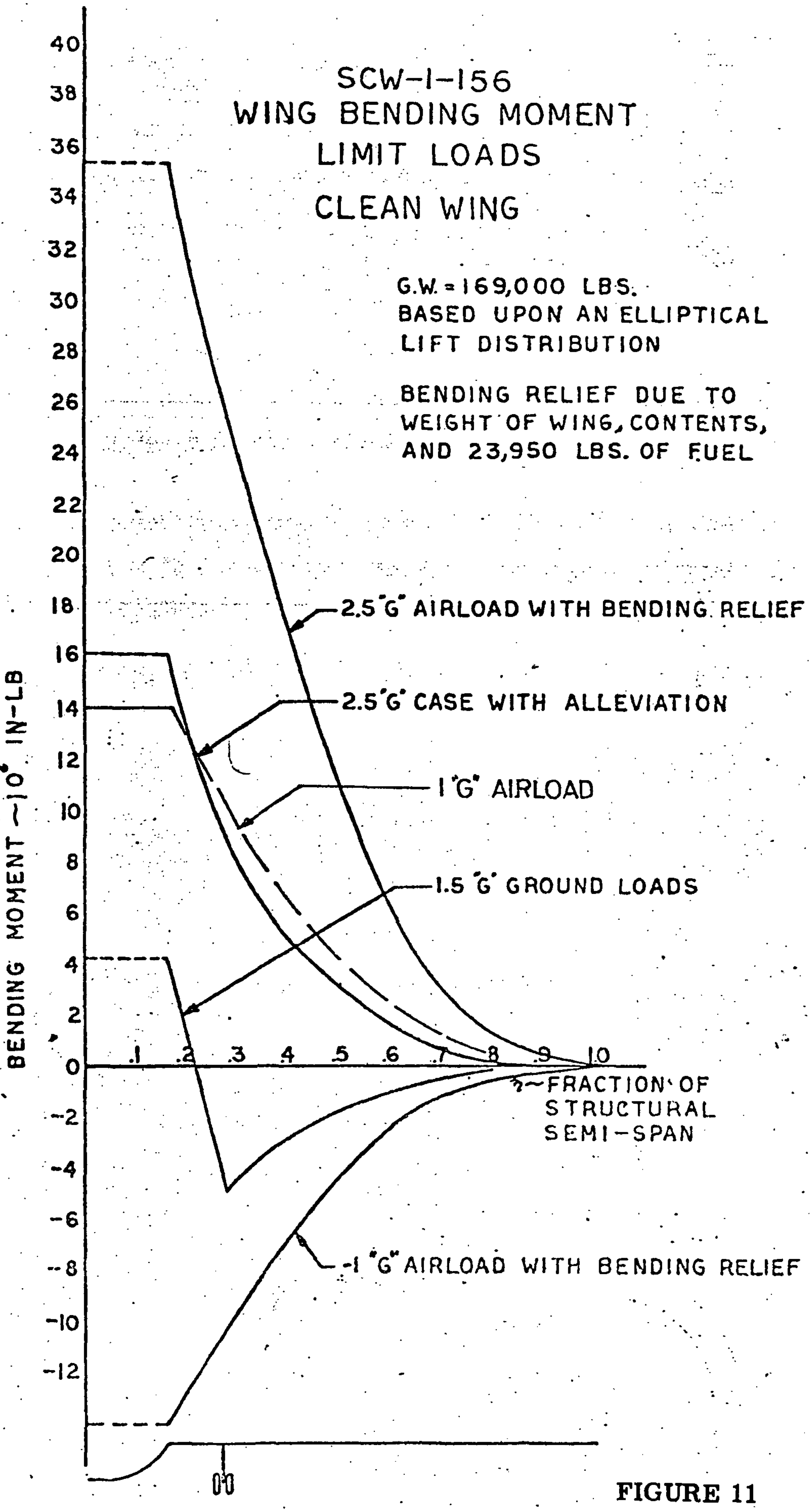

SCW-I-156
WING BENDING MOMENT
LIMIT LOADS
CLEAN WING
G.W. = 169,000 LBS.
BASED UPON AN ELLIPTICAL
LIFT DISTRIBUTION
BENDING RELIEF DUE TO
WEIGHT OF WING, CONTENTS,
AND 23,950 LBS. OF FUEL
2.5 'G' AIRLOAD WITH BENDING RELIEF
2.5 'G' CASE WITH ALLEVIATION
1 'G' AIRLOAD
1.5 'G' GROUND LOADS
-1 'G' AIRLOAD WITH BENDING RELIEF
BENDING MOMENT ~ 10^6 IN-LB
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
η ~ FRACTION OF
STRUCTURAL
SEMI-SPAN

FIGURE 11

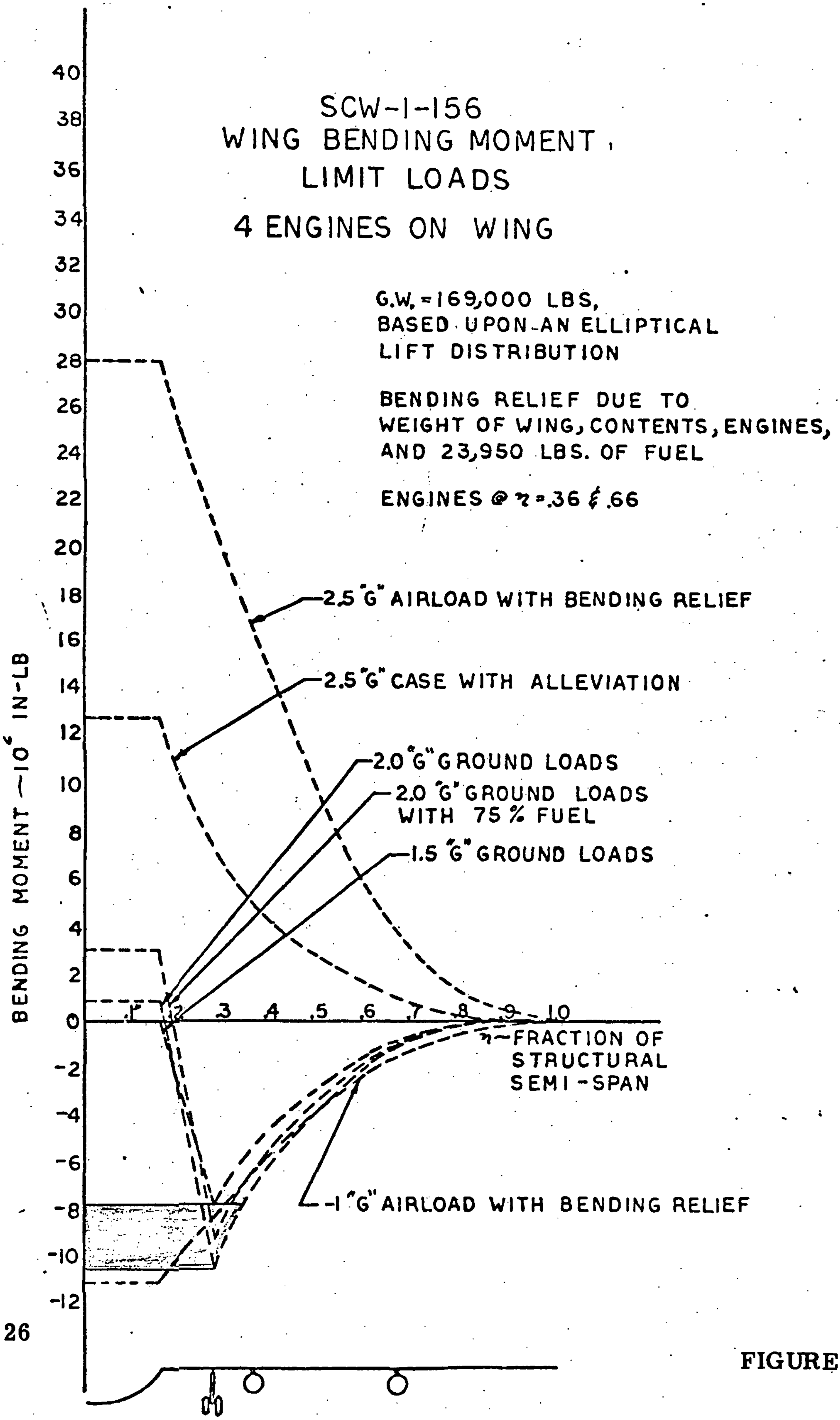

SCW-1-156
WING BENDING MOMENT
LIMIT LOADS
4 ENGINES ON WING
G.W. = 169,000 LBS.
BASED UPON AN ELLIPTICAL
LIFT DISTRIBUTION
BENDING RELIEF DUE TO
WEIGHT OF WING, CONTENTS, ENGINES,
AND 23,950 LBS. OF FUEL
ENGINES @ η = .36 & .66
2.5 "G" AIRLOAD WITH BENDING RELIEF
2.5 "G" CASE WITH ALLEVIATION
2.0 "G" GROUND LOADS
2.0 "G" GROUND LOADS
WITH 75 % FUEL
1.5 "G" GROUND LOADS
-1 "G" AIRLOAD WITH BENDING RELIEF
BENDING MOMENT — 10⁶ IN-LB
η — FRACTION OF
STRUCTURAL
SEMI-SPAN
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

FIGURE 12

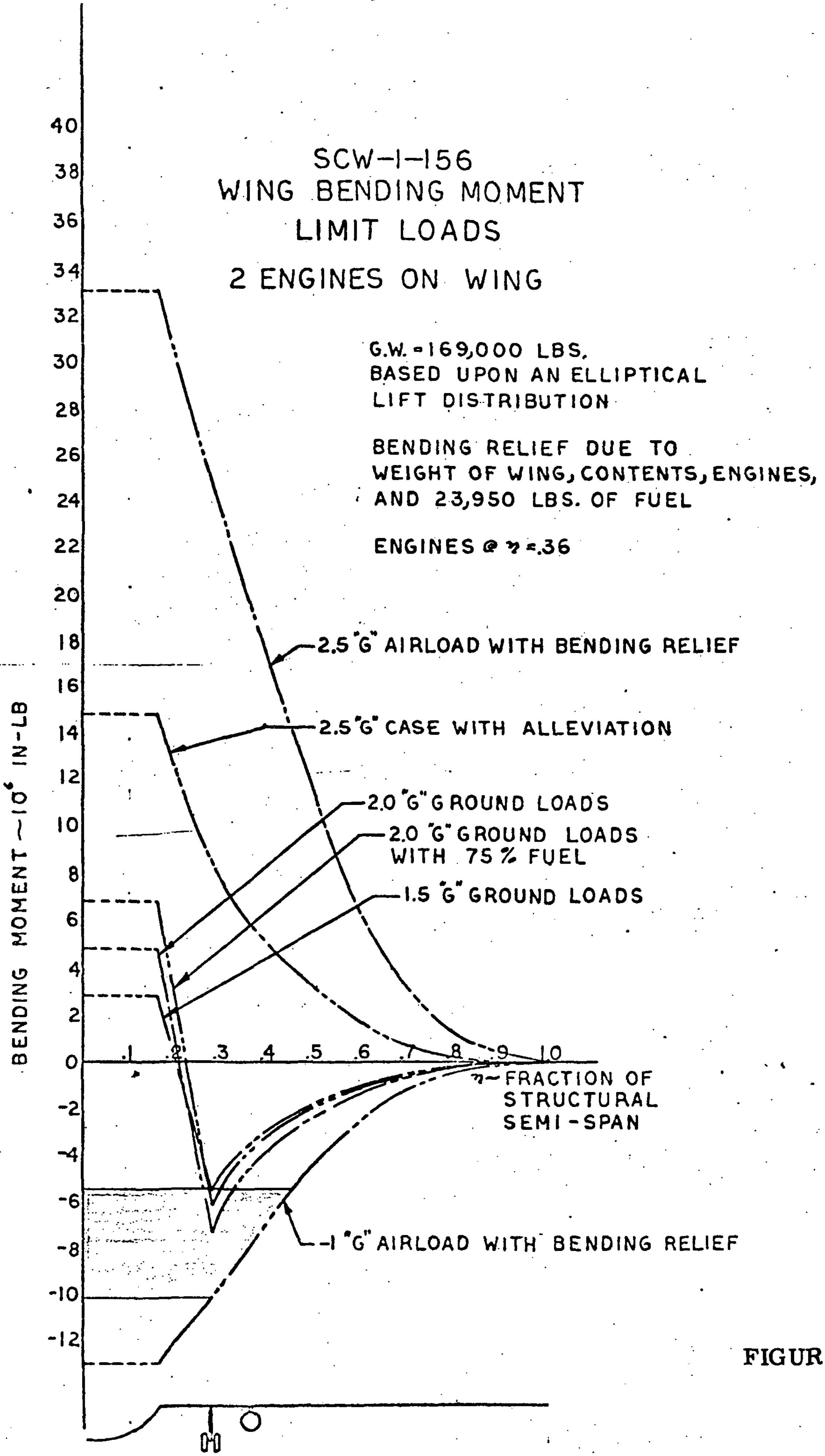
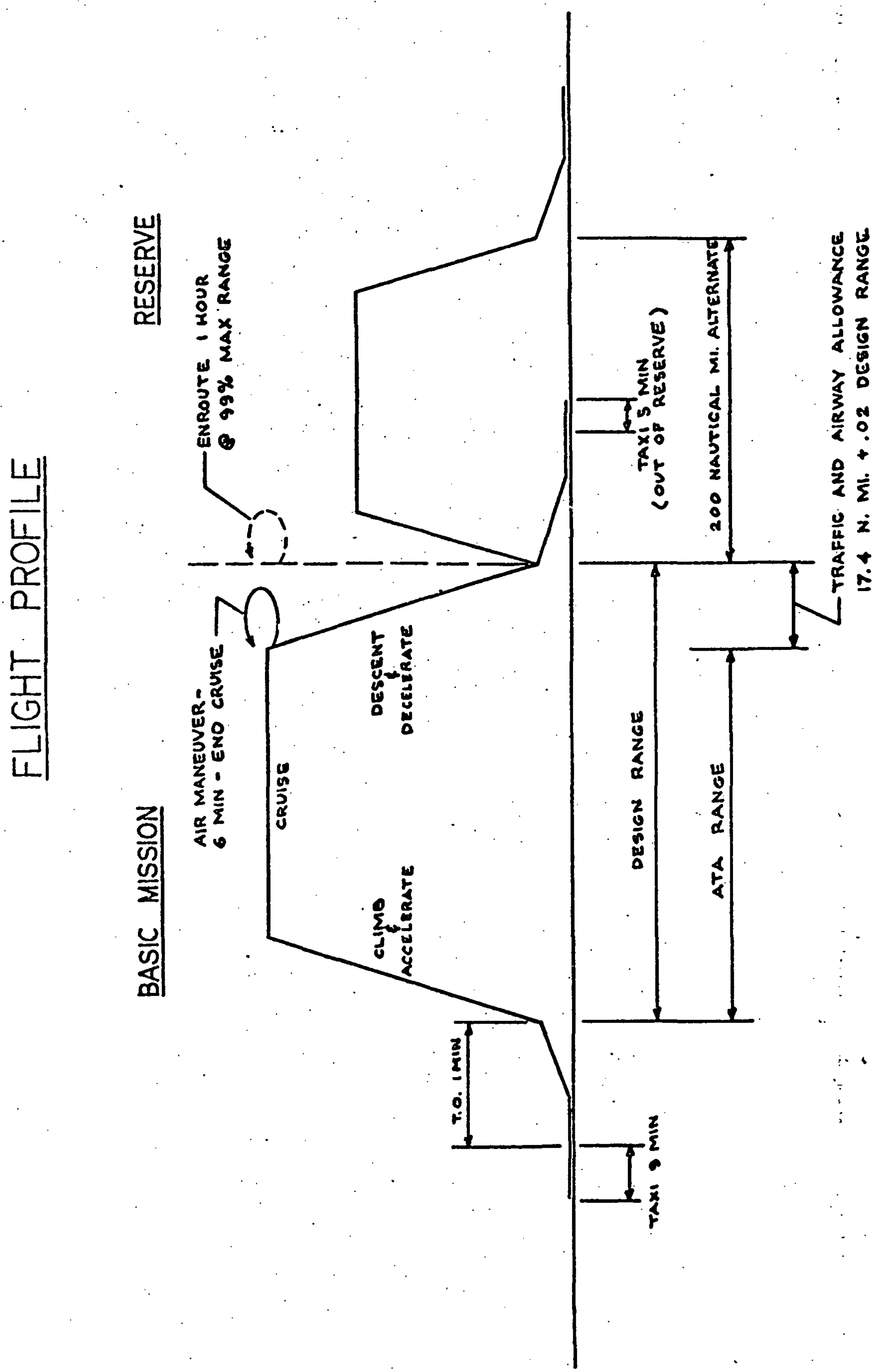

SCW-1-156
WING BENDING MOMENT
LIMIT LOADS
2 ENGINES ON WING
G.W. = 169,000 LBS.
BASED UPON AN ELLIPTICAL
LIFT DISTRIBUTION
BENDING RELIEF DUE TO
WEIGHT OF WING, CONTENTS, ENGINES,
AND 23,950 LBS. OF FUEL
ENGINES @ η = .36
2.5 "G" AIRLOAD WITH BENDING RELIEF
2.5 "G" CASE WITH ALLEVIATION
2.0 "G" GROUND LOADS
2.0 "G" GROUND LOADS
WITH 75% FUEL
1.5 "G" GROUND LOADS
-1 "G" AIRLOAD WITH BENDING RELIEF
BENDING MOMENT — 10⁶ IN-LB
η ~ FRACTION OF
STRUCTURAL
SEMI-SPAN
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

FIGURE 13

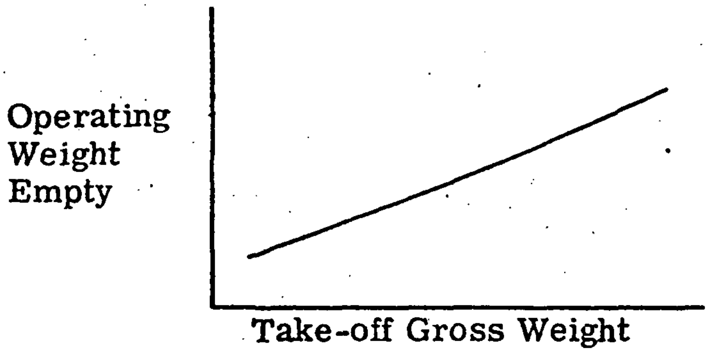


FLIGHT PROFILE
BASIC MISSION
RESERVE
AIR MANEUVER - 6 MIN - END CRUISE
ENROUTE 1 HOUR @ 99% MAX RANGE
CRUISE
CLIMB & ACCELERATE
DESCENT & DECELERATE
T.O. 1 MIN
TAXI 9 MIN
TAXI 5 MIN (OUT OF RESERVE)
DESIGN RANGE
ATA RANGE
200 NAUTICAL MI. ALTERNATE
TRAFFIC AND AIRWAY ALLOWANCE 17.4 N. MI. + .02 DESIGN RANGE

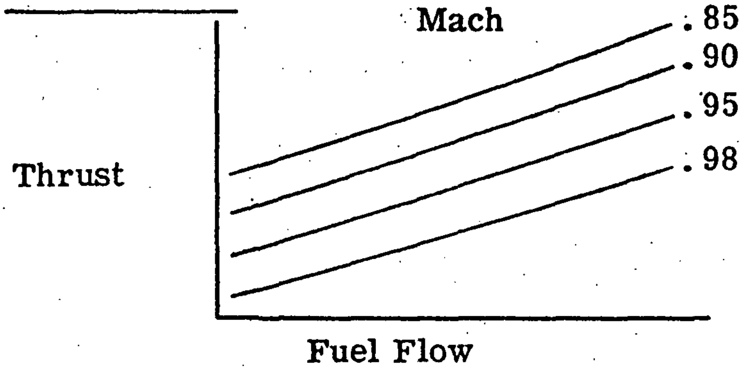
FIGURE 14

MISSION PROGRAM INPUTS

I. WEIGHTS



II. PROPULSION



III. AERODYNAMICS

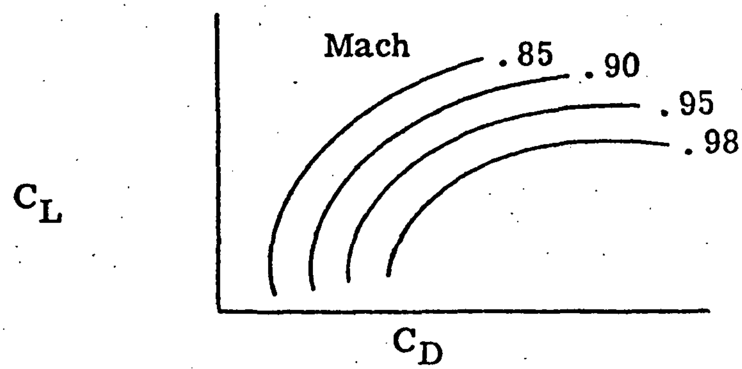


FIGURE 15

MISSION PROGRAM OUTPUTS

WEIGHTS

- Ramp
- Take-off Gross
- Start Climb
- Start Cruise
- End Cruise
- End Descent
- Zero Fuel Weight
- Operating Weight Empty

RANGE

- Segments
- Design
- ATA Allowances
- Air Transport Association

FUEL

- Segments
- Total
- Block
- Reserve

TIME

- Segments
- Flight
- Block

FIGURE 16

OPTIONS OF COMPUTER PROGRAM

TOTAL MISSION - Fixed Geometry, Payload, and Mach Number

a) Range Computed for Fixed Ramp Weight

b) Ramp Weight Computed for Fixed Range

CLIMB - Climb Speed Schedule Computed for Maximum Rate of Climb

CRUISE - Constant Mach Number

a) Optimum Climb Cruise (Maximum Specific Range)

b) Constant Altitude

c) Maximum Power Setting Climb Cruise

DESCENT

a) Predetermined Speed Schedule

b) Speed Schedule Computed for a Constant Lift Coefficient (i. e., C_L for L/D Maximum)

RESERVES

a) Air Transport Association Domestic Rules

b) Fixed Time

FIGURE 17

FUTURE CAPABILITIES AND DEVELOPMENTS

I. MISSION COMPUTER PROGRAM

A. Climb

Predetermined Speed Schedule

Maximum Energy

B. Cruise

Step Climb

C. Reserves

ATA International Rules

D. Total Mission

Engine Sizing Routine

II. AIRPORT PERFORMANCE COMPUTER PROGRAMS

A. Take-off

Distances - ground roll and air segment

Balanced Field Lengths

Speeds - take-off and obstacle

Climbout Gradients

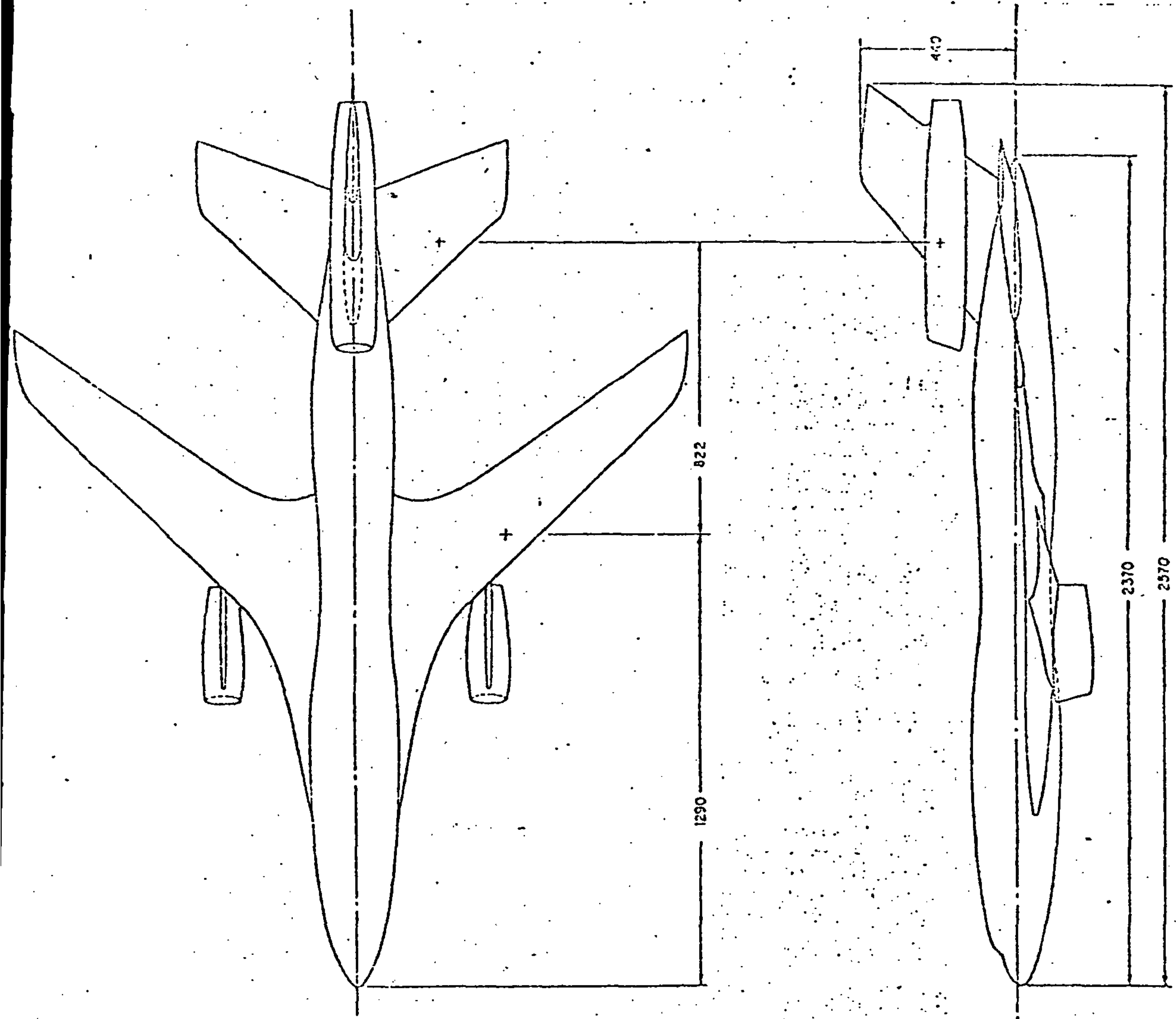
B. Landing

Distances - ground roll and air segment

Approach Speeds

Touchdown Speeds

FIGURE 18



TRIJET CONFIGURATION
300 Passenger
Mach = 0.98

FIGURE 19

VARIATION OF RAMP WEIGHT WITH WING AREA
AND START CRUISE ALTITUDE
300 PASSENGER
PAYLOAD = 61, 500 LBS.
(3) P&WA ATT-6 ENGINES
RANGE = 3000 N. MI.
MACH = 0.98

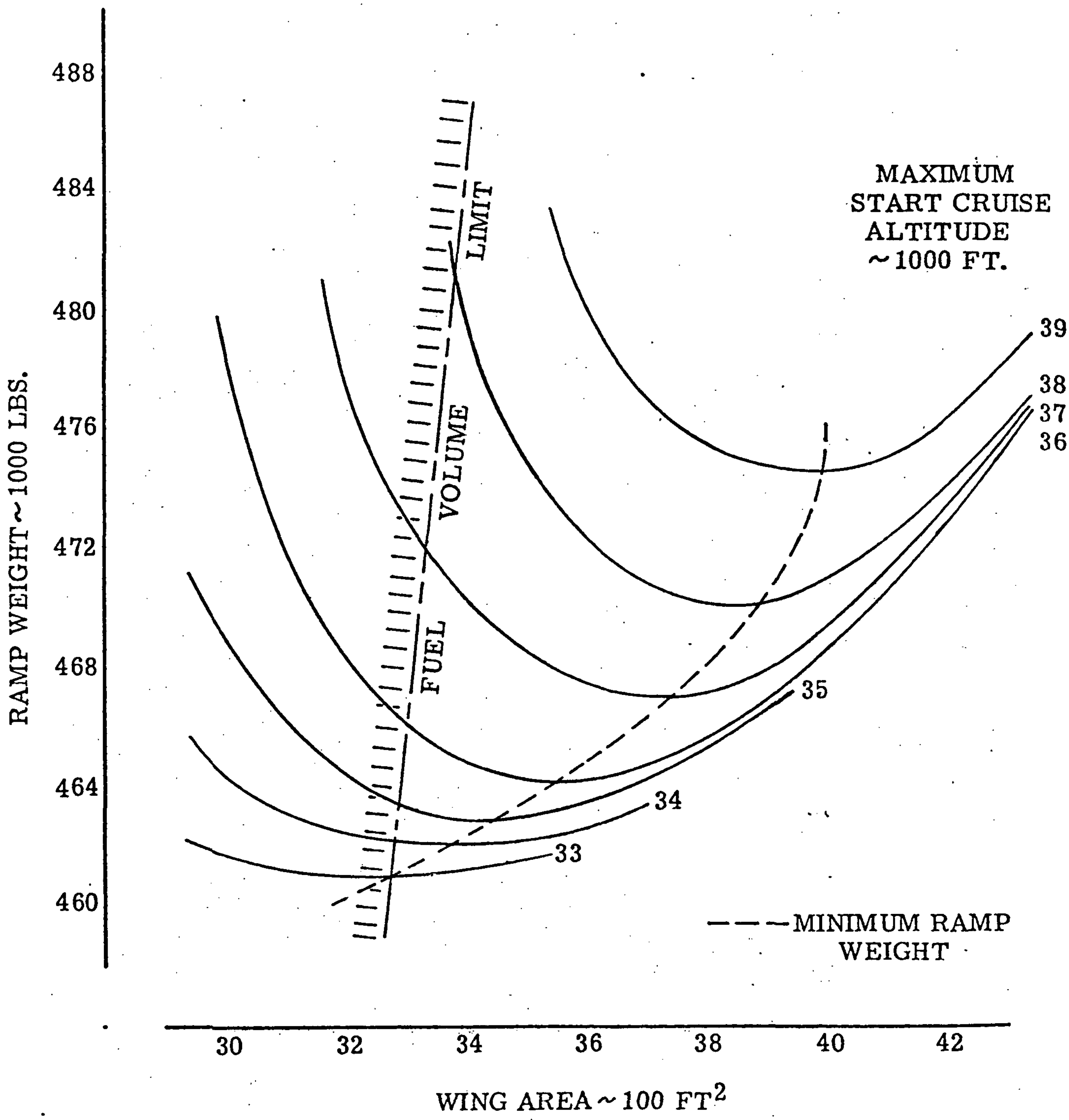


FIGURE 20

TRIJET
VARIATION OF SEA LEVEL STATIC THRUST WITH
WING AREA AND START CRUISE ALTITUDE
300 PASSENGER
PAYLOAD = 61, 500 LBS.
(3) P&WA ATT-6 ENGINES
RANGE = 3000 N. MILES
MACH = 0. 98

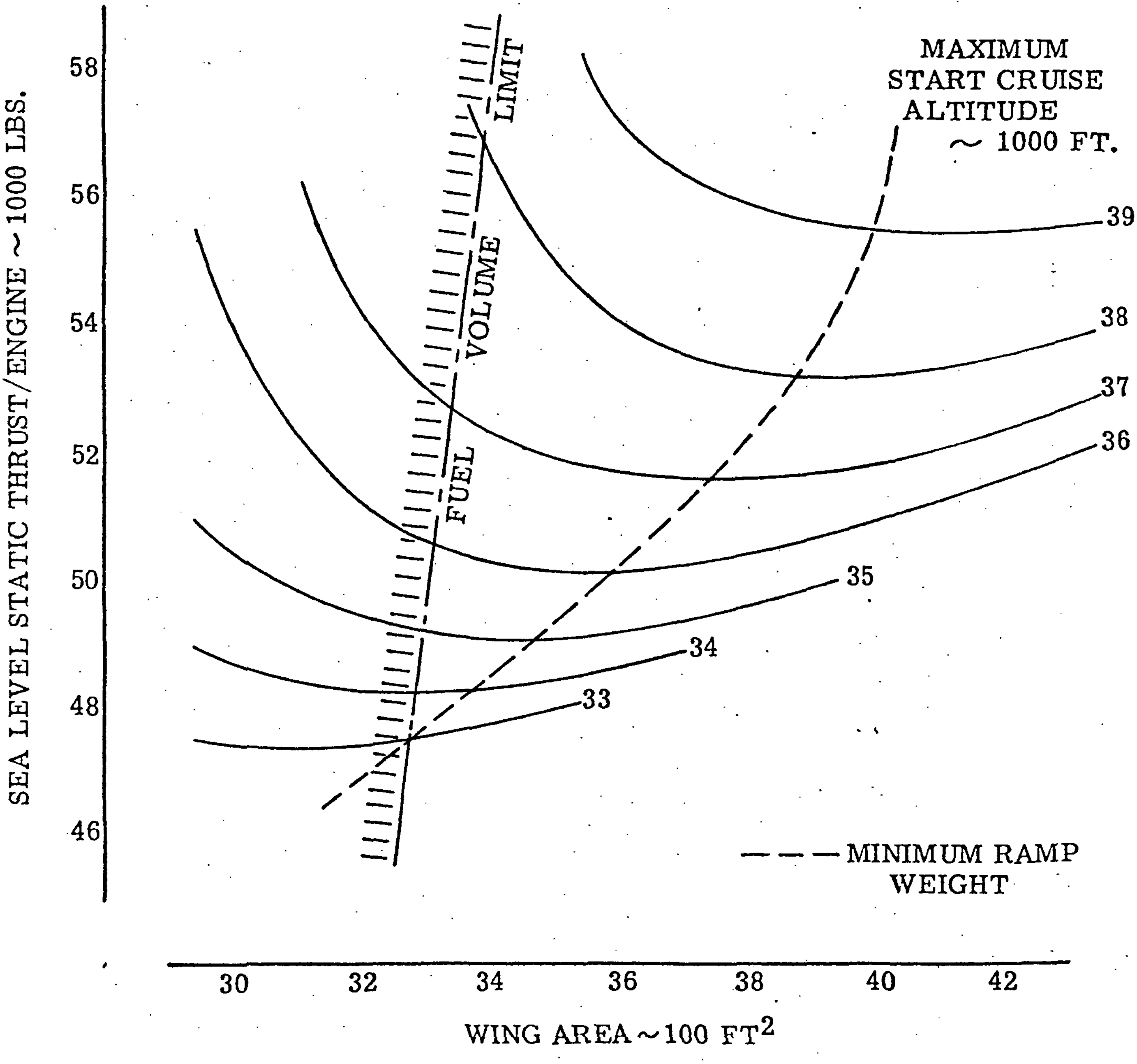


FIGURE 21

TRIJET
ALTITUDE OPERATING REGION
300 PASSENGER
PAYLOAD = 61,500 POUNDS
(3) P&WA ATT-6 ENGINES
WING AREA = 3540 FT^2
MACH = 0.98
WEIGHT = 450,000 LBS.

50,000 LBS. SEA LEVEL STATIC THRUST/ENGINE

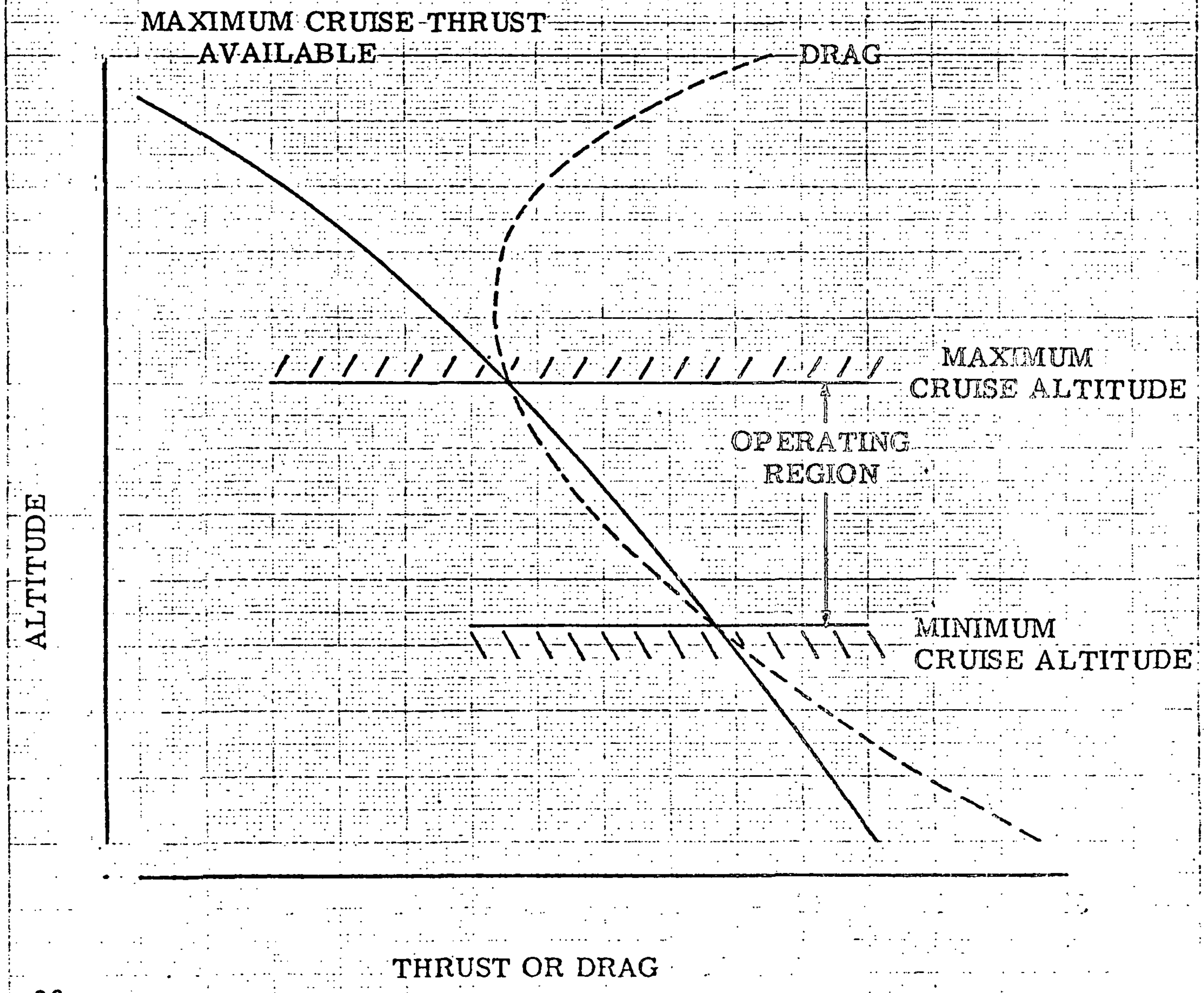


FIGURE 22

TRIJET

EFFECTS OF ENGINE SIZE ON
ALTITUDE OPERATING REGION

300 PASSENGER

PAYLOAD = 61,500 POUNDS

(3) P&WA ATT-6 ENGINES

WING AREA = 3540 FT^2

MACH = 0.98

WEIGHT = 450,000 LBS.

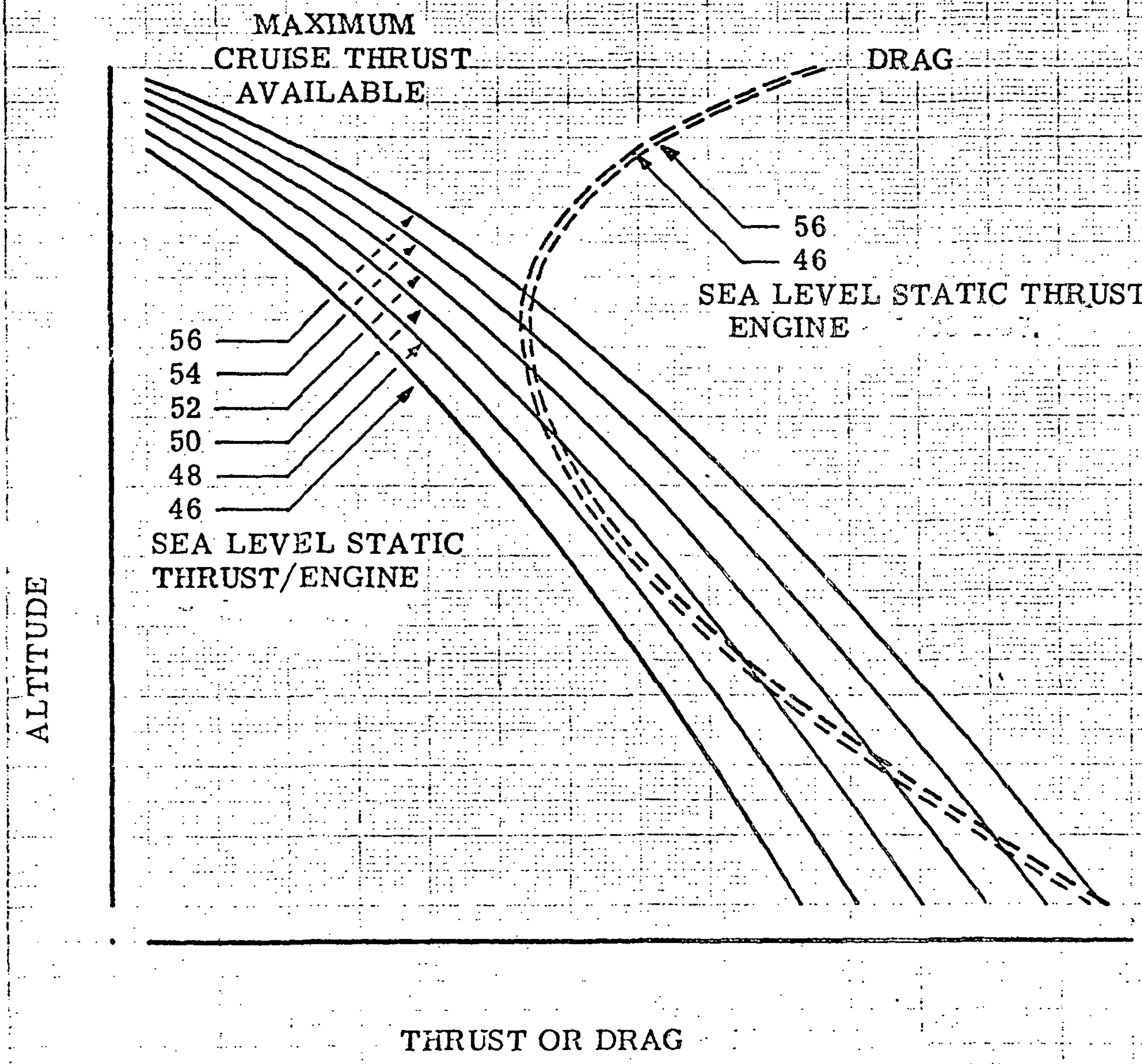


FIGURE 23

TRIJET

VARIATION OF SPECIFIC RANGE WITH ALTITUDE

(3) P&WA ATT-6 ENGINES

SEA LEVEL STATIC THRUST = 50,000 LBS/ENGINE

WING AREA = 3540 FT^2

MACH = 0.98

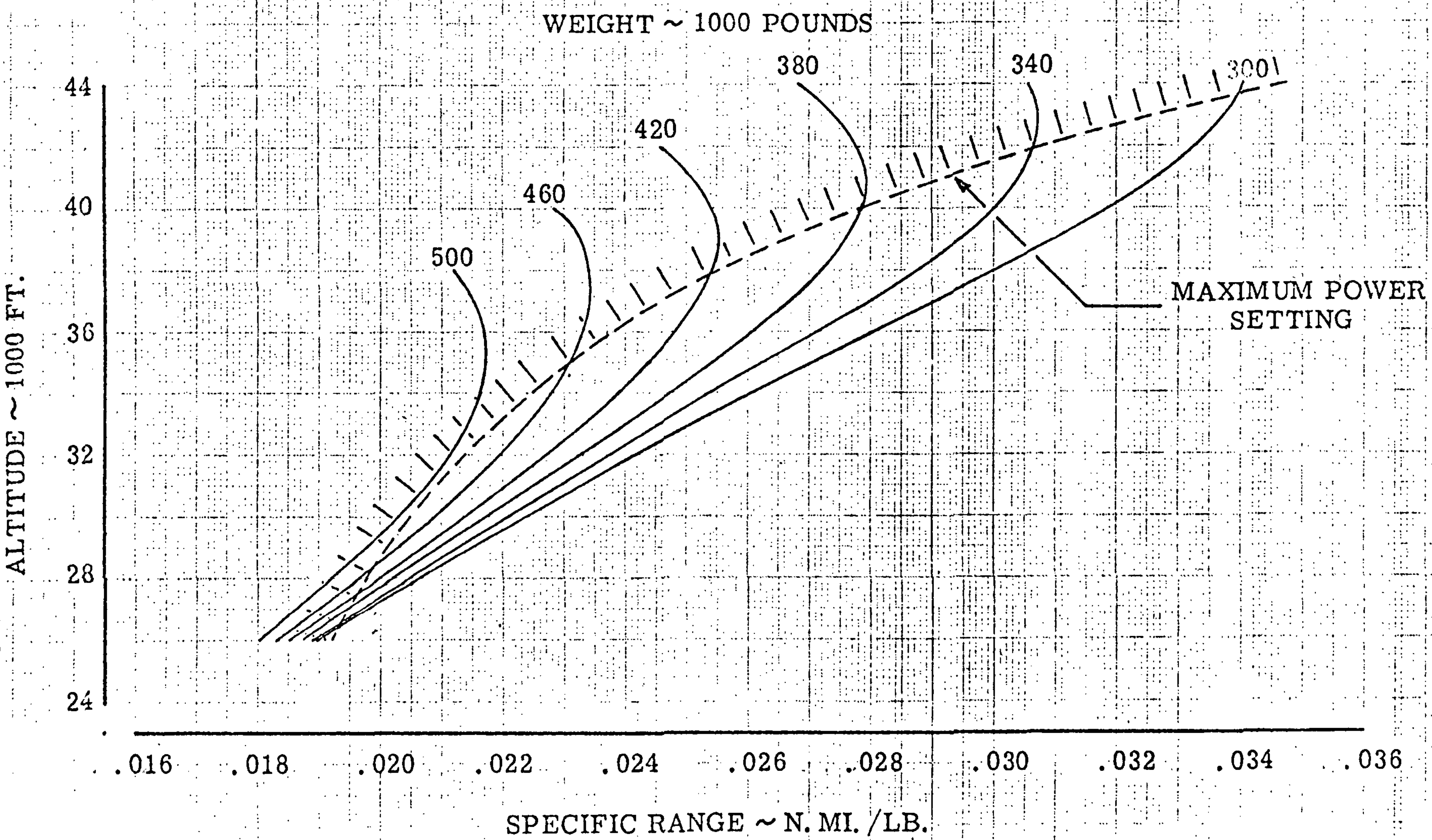
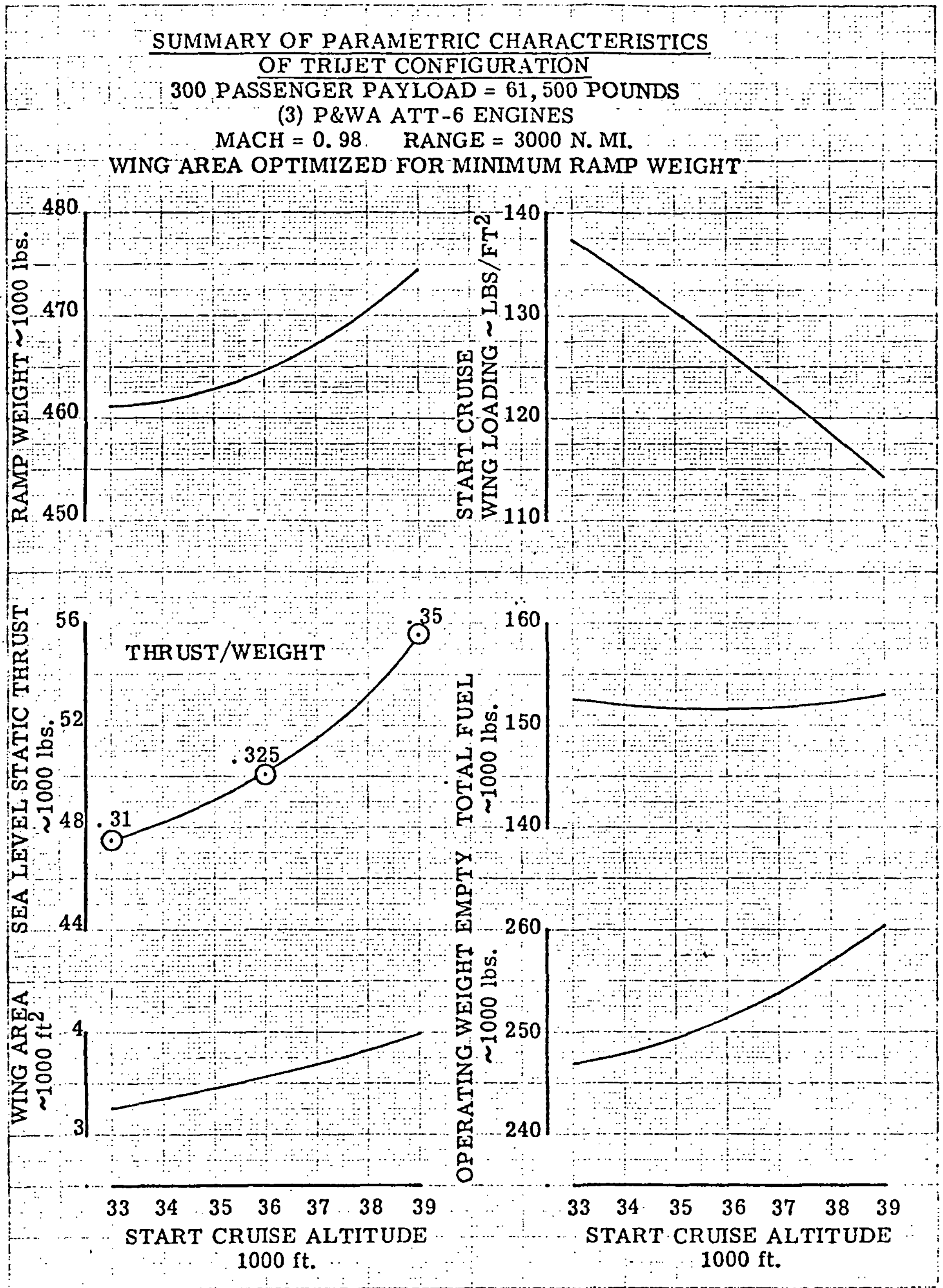


FIGURE 24



SUMMARY OF PARAMETRIC CHARACTERISTICS
OF TRIJET CONFIGURATION
300 PASSENGER PAYLOAD = 61,500 POUNDS
(3) P&WA ATT-6 ENGINES
MACH = 0.98 RANGE = 3000 N. MI.
WING AREA OPTIMIZED FOR MINIMUM RAMP WEIGHT
RAMP WEIGHT ~1000 lbs.
480
470
460
450
START CRUISE WING LOADING ~ LBS/FT^2
140
130
120
110
SEA LEVEL STATIC THRUST ~1000 lbs.
56
52
48
44
THRUST/WEIGHT
.31
.325
.35
TOTAL FUEL ~1000 lbs.
160
150
140
WING AREA ~1000 ft^2
4
3
OPERATING WEIGHT EMPTY ~1000 lbs.
260
250
240
33 34 35 36 37 38 39
START CRUISE ALTITUDE
1000 ft.
33 34 35 36 37 38 39
START CRUISE ALTITUDE
1000 ft.

FIGURE 25

CONTRACTOR STUDY AIRCRAFT GEOMETRY COMPARISON

Contractor	GELAC	GELAC	CONVAIR	CONVAIR	CONVAIR	BOEING	BOEING	BOEING
Designation	NASA HiPerf.	Alternate	Conventional	Alternate	Hi Perf.	767-640	767-630	767-620
Payload (lb)	90,000	150,000	40000	40000	40000	40000	40000	40000
Range (NM)	5,000	2,800	3000	3000	3000	3000	3000	3000
Speed (M)	.98	.85	.82	.90	.98	.90	.95	.98
TOGW (lb)	649,600	566,600	304,800	247,432	273,840	303,700	320,000	340,600
OWE (lb)	258,500	250,550	163,554	127,938	144,128	159,500	171,290	184,840
Area (S) (ft^2)	4630	4063	2540	1970	2282	2260	2450	2690
Aspect Ratio (AR)	6.28	8.50	6.8	9.0	8.0	7.6	6.9	6.4
Wing Loading - (W/S) #/ft^2	134.8	134.9	120	125.6	120	134.3	130.6	126.6
Span (b) Ft	172.3	185.0	131.5	139.8	141.8	132.0	127.8	129.7
Length (l) ft.	248.75	268.	169.8	172.1	193.6	165.6	171.2	181.7
Sweep-back (Λ)	41.4°c/4	30°c/4	35°c/4	36°c/4	40°c/4	36.5°c/4	40°c/4	42.2°c/4
Thrust (lb)	209,100	143,600	80,280	68,200	79,440	93,900	102,900	116,400
Engine Location	2W-1T	4W	2W-1T	2W-1T	2W-1T	2W-1T	2W-1T	2W-1T

NASA-Langley Form 10 (AUG 1969)

TABLE I

TABLE II

COMPUTER PROGRAMS EMPLOYED IN ADVANCED TRANSPORT TECHNOLOGIES

NAME	TITLE	FUNCTION
		AERODYNAMICS
SGAD	Surface Geometry and Area Distribution	Provides wing geometry definition and body area rule solution including lift compensation effects.
		STATIC AND DYNAMIC LOADS
AINT	Area Integration Program	Generalized program to integrate and plot areas under any curve formed by 2-dimensional set of data points. Also computes resultant shears and moments about any selected point.
MODES	Calculates structural influence coefficients	Program determines the normal coupled or uncoupled cantilevered or symmetric modes for an airfoil.
ABACUS	Airfoil flutter parameters	Calculates the flutter index and mass ratio parameters for a particular airfoil configuration.
NORMAL	Airfoil flutter parameters	Prepares aerodynamic wind tunnel data for use in flutter programs.

TABLE II (Continued)

NAME	TITLE	FUNCTION
MISSION ANALYSIS		
MISSION	Mission Analysis	Calculates complete segmented mission analysis (time, distance, fuel and weights) for climb, cruise, descent, and reserves.
TAKEOFF	Take off field length	Calculates balanced field length take-off.
DRAG	Parasite drag	Calculates skin friction (parasite) drag using flat plate theory.
LANDING	Landing distance and field length	Calculates approach conditions, flare, distance and time, and ground run.
INSTALLED ENGINE PERFORMANCE		
BINPEP - 9D-7	Basic installed engine performance Pratt and Whitney Aircraft engines	Corrects uninstalled engine performance for installation effects.
SINPEP - ATT6 STF-429 STF-433	Simplified installed engine performance - Pratt and Whitney Aircraft engines.	Corrects uninstalled engine performance for installation effects.
BINGEP R72AE6167 NASA	Basic installed engine performance - General Electric ATT Study engines	Provides uninstalled or installed engine performance for GE-ATT study engines only.
GENENG NASA TND-6552	Generalized engine performance computer program	Calculates design and off-design performance for turbojet and turbofan engines.
GENENG II NASA TND-6553	Generalized engine performance computer program	Calculates design and off-design performance for two and three spool turbofans with as many nozzles.

TABLE II (Continued)

STRESS ANALYSIS

NAME	TITLE	FUNCTION
NASA A3182 D. C.	Linear Laminate Analysis	Determines the critical load for a given fiber orientation.
LAMOPT NASA A3561 D. C.	Laminate optimization program	Determines the optimum fiber orientation for a given applied load.
SQ-5 NASA A3446 D. C.	Laminate stress analysis program	Determines elastic moduli, allowable load, internal stresses in each ply, critical loads, interaction diagram data.
PANBUCK NASA A3212 D. C.	Stability analysis of advanced filamentary composite panels	Determines the buckling stresses for rectangular orthotropically laminated composite plates and honeycomb sandwich panels.
SAWBOX	Stress analysis wing box	Determines the internal loads, stresses, margins of safety at selected spanwise stations of a wing box caused by external loads.
GRITSBOX	Wing box grid coordinate program	Calculates the grid point locations in rectangular coordinates based on the intersections of both normal and streamwise wing sections with three spanwise lines.
BUCLASP NASA A3668 D. C.	Buckling of orthotropic stiffened plates	Solves for the critical buckling load on stiffened plates built up of orthotropic laminated flat plate elements as well as beam elements.

TABLE II (Continued)

WEIGHTS AND COSTS

NAME	TITLE	FUNCTION
REGANA	Multiple regression analysis	Derives the statistically based, best curve fit equations used in weight prediction.
ESBULL	Aircraft weight, balance, and inertia	Based on statistically derived equations, predicts aircraft weight, balance, and moments of inertia.
ATTCOST	Aircraft costing	Predicts aircraft costs based on weight data inputs generated by program ESBULL.